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Utilizing the Public on Public Lands: The Application of Community Science to Monitor and Model Erosion in National Forests

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Utilizing the Public on Public Lands:

The Application of Community Science to Monitor and Model Erosion in National Forests

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by

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ABSTRACT

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Unpaved forest roads are adversely affecting coldwater streams through excessive erosion and the subsequent sedimentation of adjacent waterways. To help identify areas of concern, Trout Unlimited (TU) in the Southern Appalachian region developed a Community Science initiative to gather data on sediment sources and stream-road crossings. Volunteers were recruited and trained to monitor road and trail conditions and collect and submit data using a Survey123 application on their cell phones. Analysis of the contributed data reveals statistical connections between drainage type and both erosion level and stream sedimentation. The contributed data were also included as a calibration for the lite version of the Geomorphic Road Analysis and Inventory Package (GRAIP-Lite), a GIS-based road sediment contribution model. The analysis found statistically significant differences between Basic and Calibrated models at one of two sites, and substantial increases in sediment delivery from the Alternate model at both sites.

DEDICATION

The coldwater health
And sediment loads
Are under attack
By forestry roads.

A beautiful place,
A need that is new;
A collection of folks
That do what they do.

And what do they do
To help public lands?
They dive in to use
Their own public hands.

A conscious collective
Of blood, sweat and tears.
I dedicate this
To all volunteers.

ACKNOWLEDGEMENTS

This project would not have been possible without Trout Unlimited and the US Forest Service, who saw a problem and decided to tackle it. Most especially, I would like to acknowledge the dedicated community scientists, who were and still are willing to give their valuable time to collect valuable information about valuable public lands.

I would like to sincerely thank Dr. Ingrid Luffman for her constant confidence in my abilities and her continuous commitment towards my research and my understanding of data in general. I couldn’t have done this without her. I would also like to thank Drs. Andrew Joyner and Arpita Nandi, as well as the rest of the Dept. of Geosciences faculty, for their continual help anytime help was needed. A special thank you goes out to my cohort, who were always there to help work through problems, or just commiserate when needed. Finally, I would like to thank my cat, Funyuns, for reminding me that I, too, am a living creature who needs to eat.

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CHAPTER 1. INTRODUCTION

The amount of suspended sediments within freshwater systems is critical to the ecological health of aquatic ecosystems. Suspended sediments affect everything in the aquatic ecosystem, from phytoplankton, through their inability to photosynthesize sufficient energy, to invertebrates, by clogging filter-feeding structures and damaging exposed organs via scouring, to local fisheries, such as trout and salmon, by reducing developmental habitat for salmonid eggs and larvae (Bilotta and Brazier 2008). According to the United States Environmental Protection Agency, excessive sedimentation of waterways is the second-most leading cause nationwide for riparian impairment behind pathogens, with 138,874 miles and 187,872 miles threatened or impaired, respectively (EPA 2020). In North Carolina, 146 miles of rivers or streams are threatened or impaired due to excessive turbidity (decreased water clarity, which is most commonly attributed to excessive sediment) (EPA 2020).

Unsealed (or unpaved) forest roads impact the hydrological system; the greater the proximity of a forest road to a stream, the more likely it is that sediment from the road will ultimately reach the stream (Orndorff 2017). The quantity of sediment reaching nearby streams can be significantly decreased through the proper management of National Forest roads; adoption of appropriate management practices can significantly increase the ecological quality of lotic habitats (Orndorff 2017). These management decisions, when made appropriately, are data-driven (Black et al 2012). Data of these type are typically collected through monitoring and/or modeling the existing environmental conditions on National Forest roads.

Community science refers to amateur involvement in scientific programs, most often observation-based, designed specifically to incorporate contribution from non-professional scientists (Silvertown 2009). Monitoring programs that incorporate community science can be extremely useful for organizations involved in environmental monitoring and restoration, particularly where adequate funding for paid positions may not exist (Conrad and Hilchey 2011). Along with the increase of public access to mobile devices with both internet access and Global Positioning System (GPS) capabilities, this has led to a significant increase in organizations and agencies that apply technology to create a community of concerned volunteers who collect and share scientific information (Sullivan et al 2009; Connors et al 2012; Matheson 2014). Geospatially-based data collection apps such as Survey123 from the Earth Science Research Institute (ESRI) can provide an easy to use platform for community members as well as built-in databases, data visualization options, and sharing opportunities (Lamoureux and Fast 2019).

Trout Unlimited (TU) is a national, non-profit organization committed to “protecting, reconnecting, restoring and sustaining our coldwater resources” (Trout Unlimited 2020). The TU Southern Appalachian Coldwater Conservation Manager, based in Asheville, NC, developed a series of community science programs to assess and monitor various concerns for coldwater habitat health in Western North Carolina, in the Pisgah and Nantahala National Forests. Four primary data collection programs were developed in the Fall of 2018: Aquatic Organism Passage Barrier Assessment, Sedimentation Surveys, Water Temperature Sampling, and Didymo Sampling. Information from these surveys will be used to help guide management decisions within the Pisgah and Nantahala National Forests (NCTU 2019). Development and implementation of the TU community science sedimentation surveys will be discussed in Study I.

While field study is an important component of road erosion and stream sedimentation assessment, models can be a useful tool to estimate conditions in a much larger area and in a less labor-intensive manner. Sediment models can incorporate field data using a series of equations to predict long term trends or event-based erosion. Such models come in two main types: models utilizing statistical relationships based on observation and those utilizing mass and energy conservation equations to determine hydrological responses, called empirical and physics-based models, respectively (Merritt et al 2003). Regardless of the model type, most road sedimentation models include two primary components that model 1) road surface erosion rate and 2) road sediment delivery to stream networks (Fu et al 2010). Road sediment modeling will be discussed in Study II.

Research Questions and Study Objectives

This thesis consists of two separate but related studies. The first describes the TU community science sedimentation survey and compares road erosion data collected by community scientists. The second compares sedimentation model outputs when data from Study I are used as calibration in the form of known drain points on US National Forest (USFS) roads.

Study I

Objective. The objective of Study I is to train and actively engage concerned community members in data collection methods for examining and reporting erosion on unsealed forest roads. This dataset will ultimately impact on-the-ground conservation on USFS land.

Research questions. Can volunteer community members be effectively engaged to collect valuable, high-quality data on unsealed forest road erosion contributing to stream sedimentation?

Study II

Objective. The objective of Study II is to assess the viability of utilizing contributed community science data within a readily available sedimentation model on two unsealed National Forest roads. GRAIP-Lite was selected based on its suitability for National Forest roads, utility with minimal field data, and the ability to calibrate with observed drain points. This study will focus on the effects of adding additional GPS-collected drainage points to the GRAIP-Lite model.

Research questions. How does the inclusion of community-collected data into existing sedimentation models (GRAIP-Lite) affect the model's output, and what modifications can be done in an attempt to better represent conditions on the ground?

CHAPTER 2. ENGAGING THE COMMUNITY TO MONITOR EROSION AND SEDIMENTATION IN THE US NATIONAL FOREST, NORTH CAROLINA

Abstract

Trout Unlimited (TU) works to identify and remediate roads that adversely affect coldwater streams. To help identify areas of concern for stream health, a Community Science initiative was developed to gather data on sediment sources and stream-road crossings. In cooperation with the United States Forest Service and the North Carolina Wildlife Resources Commission, Survey123 forms were created and used by volunteers to provide baseline data on road condition within the Wilson Creek watershed, near Grandfather Mountain, and an area referred to as Sky Island, near Asheville, NC. Volunteers were recruited and trained in data collection and worked in teams to monitor road and trail conditions and collect data using the Survey123 app on their cell phones. Analysis of the contributed data reveals statistical connections between drainage type and both erosion level and stream sedimentation. The project produces valuable monitoring data and leverages Community Scientists as proud contributors to conservation efforts.

Introduction

River systems serve many functions in the natural world, both geologically and ecologically. One main function is found in its dynamic sedimentary system: the amount of sediment transported downstream is a function of the rate of sediment input and the amount of available storage (Lisle et al 2002). When the supply of sediment input becomes too high, the entire storage-transport system can be negatively altered. This is especially concerning in fast-flowing, gravel-bedded (or lotic) environments, which have a much lower sediment storage capacity than slower-flowing stream environments (Lisle et al 2002).

According to the United States Environmental Protection Agency, excessive sedimentation of waterways is the second-most leading cause nationwide for riparian impairment behind pathogens, with 138,874 miles and 187,872 miles threatened or impaired, respectively (EPA 2020). North Carolina reports that 146 miles of rivers or streams are threatened or impaired due to excessive turbidity (or decreased water clarity, which is most commonly attributed to excessive sediment) (EPA 2020).

The health of aquatic ecosystems is heavily affected by increased levels of sediment within freshwater systems. Suspended sediments cause a decline in fisheries and can lead to the degradation of aquatic ecosystems (Bilotta and Brazier 2008). This issue affects everything in the aquatic ecosystem, from phytoplankton, through their inability to photosynthesize sufficient energy, to invertebrates, by clogging filter-feeding structures and damaging exposed organs via scouring, to local fisheries, such as trout and salmon, by reducing developmental habitat for salmonid eggs and larvae (Bilotta and Brazier 2008).

An increase in sediment results in a decrease in fish and other aquatic organisms, to the detriment of the local ecological diversity. This can negatively impact recreational opportunities, such as sport fishing, and therefore negatively impact the economies of areas relying on ecotourism through decreased spending on, for example, fishing licenses, equipment, travel, lodging, and local guide services (Upneja et al 2012). Much of the time many of these items and services are obtained in the local community. Ironically, public access to areas of ecological value can be a significant contributing factor to the degradation of the ecosystem, mainly due to road construction and use (Croke and Hairsine 2006).

Unsealed Forest Roads

Excessive sedimentation of streams and rivers can be a problem anywhere human infrastructure exists. Human activities related to land use, irrigation, reservoir construction, and other activities have disrupted natural riparian processes (Miao et al 2011). Anthropogenic environmental alterations have caused an increase in riparian soil erosion while at the same time causing a decrease in the flux of sediment reaching the oceans (Syvitski et al 2005). Deforestation and other forestry practices have a significant impact on erosion and, subsequently, the sedimentation of streams and rivers (Zhang 2009).

Increased stream sedimentation is well demonstrated for unsealed (unpaved) forest roads (Croke and Hairsine 2006). The distance between a road and stream is inversely proportional to the amount of sediment that reaches a stream, and stream crossings contribute more sediment to streams than any other land management activity (Orndorff 2017). Proper management of National Forest roads can significantly decrease the quantity of sediment reaching nearby streams, and significantly increase the ecological quality of lotic habitats.

Forest roads impact hydrology by three different methods: intercepting water that would otherwise infiltrate the ground, concentrating water into a flowing channel in an adjacent ditch or on the road itself, and diverting water along the grade of the road, possibly discharging it straight into a stream (Orndorff 2017). Among the biggest issues to consider regarding unsealed forest roads involves the channeling of water on the road surface. Advective flows (water flowing through channels) can travel two to three times further before depositing sediment than dispersive flows (flowing water which spreads out) (Orndorff 2017).

Proper Best Management Practice (BMP) planning can help greatly reduce the contribution of sediment being supplied to the stream. Examples of common BMP's on forest roads include: forested buffers between roads and streams to reduce their hydrologic connectivity, avoidance of stream crossings for forest roads, construction of forest roads on lower slope areas, and adequate placement of road drainage features to divert water away from the roadway (Orndorff 2017). Implementation of these and other practices can help considerably in reducing the quantity of sediment reaching the stream from the road (Orndorff 2017).

Community Science

Community science (or citizen science), simply put, is scientific contribution from everyday people with an interest in scientific study. Indeed, throughout much of history most scientists were, in effect, community scientists, including many notable scientists with many laudable achievements (Silvertown 2009). In essence, a community scientist is a scientist 'who has not quit their day job,' one who practices the scientific process (or a portion thereof) without the incentive of financial compensation. Realistically and in their modern implication, the terms 'citizen science' and 'community science' refer to scientific programs designed specifically to incorporate amateur involvement in a portion of a study, usually observation-based (Silvertown 2009).

Aside from obvious benefits in the quantity of available data, community science programs can create a substantial and lasting effect on the education and social capital of the community related to the issue on which the individual program focuses – indeed, to many programs this aspect is even more important than the data itself (Conrad and Hilchey 2011). Social capital, or the amount of connection that individuals experience within a specific community, is fostered by providing a meaningful task for community scientists, creating a sense of ownership and thereby a greater understanding and affinity towards the issue at hand (Conrad and Hilchey 2011). This combination can promote not only education of the community scientist, but also education of their social networks and a greater understanding of the issue in the community at large, increasing the chance of public funding and stewardship.

Perhaps the most famous and earliest application of a program like this is the Christmas Bird Count (CBC) directed by the National Audubon Society. Beginning in 1900 and continuing to this day, the CBC has amassed a considerable amount of data relating to the status of North American bird species; these data have been used in nearly 350 published papers and led to increased scientific understanding of various bird species and the anthropogenic impact on their populations (Silvertown 2009).

A second example is the Community Collaborative Rain, Hail, and Snow (CoCoRaHS) network, an ongoing precipitation monitoring initiative begun in 1997 with the dual purpose of collecting precipitation data and encouraging weather awareness in the community (Reges et al 2008). More than twenty years later, the collaborative has almost 20,000 volunteers who submit precipitation data used by researchers, teachers, and hobbyists alike to track storms and weather and climate patterns, and is sponsored by the National Oceanic and Atmospheric Administration (NOAA) and the National Science Foundation (NSF) (CoCoRaHS 2020).

Community science can be an extremely useful tool for monitoring trends where sufficient funding may not exist to support paid positions (Conrad and Hilchey 2011).

Recognition of this along with the success of programs like the CBC and CoCoRaHS has led numerous organizations and agencies to adopt community science programs of their own. This is perhaps most obvious in the environmental and ecological fields, particularly those requiring a large amount of field-based observations (Silvertown 2009). This benefits the scientists' understanding of the issue through data, the communities' understanding of the issue though education, and the communities' social capital for the issue through involvement in the management process.

Geospatial applications in community science. In recent years, a dramatic increase in community-based science and monitoring has been possible, largely due to technological advances (Connors, Lei and Kelly 2012). The proliferation of mobile devices with both internet access and Global Positioning System (GPS) capabilities has led to widespread access to a powerful data collection tool (Connors, Lei and Kelly 2012). Web-based applications allow for the collection of relatively precise locational data along with other pertinent information.

An increasing level of experience in the general populace also provides an increased level of familiarity with tools that have previously been more specialized (Connors, Lei and Kelly 2012). Recreational-grade handheld GPS units, for instance, are a specialized tool requiring some familiarity to operate correctly; modern-day mobile devices are typically as accurate, easier to use, and also perform other tasks, such as data collection, photography, and data submission. Community science apps such as iNaturalist and eBird utilize the internet to create a community of observers who collect and share information about the natural world (Matheson 2014; Sullivan et al 2009).

Survey123, a commercial application of the Earth Science Research Institute (ESRI) connected through ArcGIS Online, is a geospatially-based data collection application

(Lamoureux and Fast 2019). Although an ArcGIS Online license is required to build and distribute survey forms, the Survey123 Field App can be downloaded for free and used by anyone, making this a great tool for community-based monitoring. The Survey123 Field App works on both Android and IOS devices, and provides a built-in database within ArcGIS Online, providing relatively extensive data visualization and sharing opportunities (Lamoureux and Fast 2019).

Challenges: involvement and accuracy. The biggest issues of any community-based data collection initiative involve promoting initial and continued involvement of volunteers and assuring the quality of volunteer data. Many organizations have difficulty garnering enough interest to recruit volunteers and, once volunteers are initially found and trained, keep them interested enough to continue submitting data (Conrad and Hilchey 2011).

Additionally, contributed data from volunteers are not necessarily reliable without additional efforts to monitor data quality. While data of questionable quality may be accurate enough to draw general conclusions, the data individually will likely not be as accurate as those collected with a traditional scientific approach (Gardiner et al 2012). Sampling bias can be a problem in crowd-sourced data. Untrained volunteers may neglect to submit absence data because it may not seem important; the reality is that reporting of any scenario, including absence of observations, can help paint a fuller picture (Robson 2012). One way to help the quality of individual data points is to encourage or require an in-person training before volunteers are allowed to submit data (Robson 2012). Furthermore, the quantity of data that can be gathered from a community science project can be aggregated to great accuracy (Robson 2012).

The objective of Study I is to train and actively engage concerned community members in data collection methods for examining and reporting erosion on unsealed forest roads. This dataset will ultimately affect on-the-ground conservation on USFS land.

Background

Trout Unlimited (TU) is a national, non-profit organization committed to "protecting, reconnecting, restoring and sustaining our coldwater resources" (Trout Unlimited 2020). The Southern Appalachian Conservation program within TU utilizes a "top-down approach" to conservation, in which waterways near the top of the hydrological system are targeted first, and downstream areas are subsequently addressed (Trout Unlimited 2020). This maximizes the amount of pristine habitat through a focus on headwater streams.

The TU Southern Appalachian Coldwater Conservation Manager, based in Asheville, NC, developed a series of community science programs to assess and monitor various concerns for coldwater habitat health in Western North Carolina, in the Pisgah and Nantahala National Forests. Four primary data collection programs were developed: Aquatic Organism Passage Barrier Assessment, Sedimentation Surveys, Water Temperature Sampling, and Didymo Sampling. Information from these surveys will be used to help guide management decisions within the Pisgah and Nantahala National Forests (NCTU 2019). This thesis focuses exclusively on the Sedimentation Survey program.

The TU Sedimentation Survey was developed to assess road- and trail-related impacts affecting stream sedimentation in western North Carolina. Community scientists were recruited and trained for this task with the dual goal of public education and collection of high-quality data. Funding for the Community Science Project was acquired, in part, by a $57,000 grant from the NC Clean Water Management Trust Fund (NCTU 2019) and supplemented by additional funding from the Land of Sky and Pisgah Chapters of Trout Unlimited and other sources, including funding and project involvement from agency partners, the United States Forest Service (USFS) and the North Carolina Wildlife Resources Commission (NCWRC) (NCTU 2019). An initial release of the Western NC Trail/Road Sedimentation Survey was first initiated in the fall of 2018, and it was redeveloped with updates to increase ease of use and functionality in the late spring of 2019. The present study covers the redevelopment and rerelease of the Western NC Trail/Road Sedimentation Survey v2.

Western NC Trail/Road Sedimentation Survey v2

The Western NC Trail/Road Sedimentation Survey was designed for use in the Survey123 Field App through a partnership between Trout Unlimited, Pisgah-Nantahala National Forest and the North Carolina Wildlife Resources Commission. An initial release of the Western NC Trail/Road Sedimentation Survey was attempted in the fall of 2018; sedimentation surveys were renewed with updates as the Western NC Trail/Road Sedimentation Survey v2 in May 2019 to increase ease of use and functionality. Questions in the Survey123 form center around locational, descriptive, or measured information and metadata about each drainage feature. A *drainage feature* is defined herein as any place of egress for water running along the road or trail prism. The *prism* refers to the surface of the road or trail in question. For more details about the survey questions, see the Mobile App Reference Guide for Community Science: Sedimentation Surveys on Trails & Roads in Appendix A.

The Survey123 Field App (Figure 2-1) is designed to host multiple survey forms at one time. Once the Western NC Trail/Road Sedimentation Survey v2 is connected to the Field App it can be selected from the Survey123 main menu. The Report Drainage Features page includes a brief description of the Sedimentation Survey goals and one or more tabs at the bottom of the page: Collect, Drafts, Outbox, and Sent. The Collect tab opens a new survey form where various data are input, beginning with metadata and ending with an image of the drainage feature.

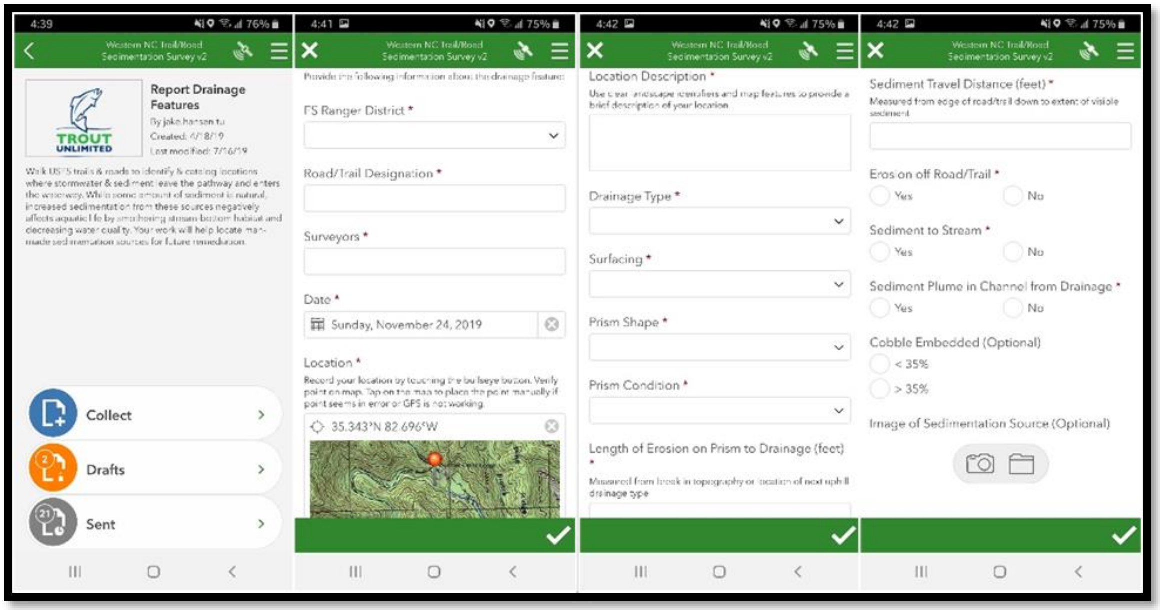

Figure 2-1. Western NC Trail/Road Sedimentation Survey v2 on the Survey123 field app for mobile devices.

Metadata and location information. Six questions in this section collect information about the road or trail being surveyed and the volunteer surveyor. These data include: the Forest Service Ranger District in which the trail is located; the Forest Service numeric designation for the particular trail being surveyed; location information using the mobile device's GPS; and, a location description, where community scientists are encouraged to describe the location of the drainage feature using landscape identifiers. The volunteer surveyor(s) name(s) and the date that the survey was conducted are also collected.

Drainage feature type and prism description. Volunteer surveyors are asked to select the specific type of drainage feature where obvious sediment is observed to be leaving the trail or road surface. The manual (see Appendix A) provides picture examples of each type of drainage feature available as an option in the Survey123 form; an 'Other' option is available as well, but volunteer surveyor are discouraged from using this unless the feature absolutely does not fit one of the categories. In this section, information on the surfacing, shape, length, and condition of the road prism is collected. This information is important in understanding the variety, direction and amount of sediment leaving the road prism. Volunteer surveyors are encouraged to take a photo of the drainage feature to provide a better sense of the specific conditions at each location. Photos of drainage features allow a moderate degree of post-collection quality assessment by the user and/or a trained scientist, and also help locate the specific drainage feature in the event it needs to be subsequently revisited.

Downslope travel and stream conditions information. In this final section, data are collected on the conditions flow path off-road. Volunteer surveyors determine the distance that sediment travels upon leaving the road prism, and whether or not additional erosion is taking place along the travel paths. They also determine whether the sediment reaches the nearest stream and, if so, whether a sediment plume exists at the point of entry. Additionally, they assess cobble embeddedness occasionally throughout the survey day, by evaluating whether cobbles in the streambed are determined to be either less than or greater than 35 percent embedded in sediment at a riffle.

Once all data are entered, the survey is submitted and the data are uploaded to the ArcGIS Online database. If the volunteer surveyor is outside internet receptivity, as is frequently the case while completing these surveys, the survey will save in the outbox to be submitted later. When this happens, volunteer surveyors must remember to manually send their outbox once internet connectivity is available.

Study Areas

TU has two main research areas in Western North Carolina: Wilson Creek watershed & an area that is referred to as "Sky Island" (Figure 2-2). These areas were the focus of the TU community science program.

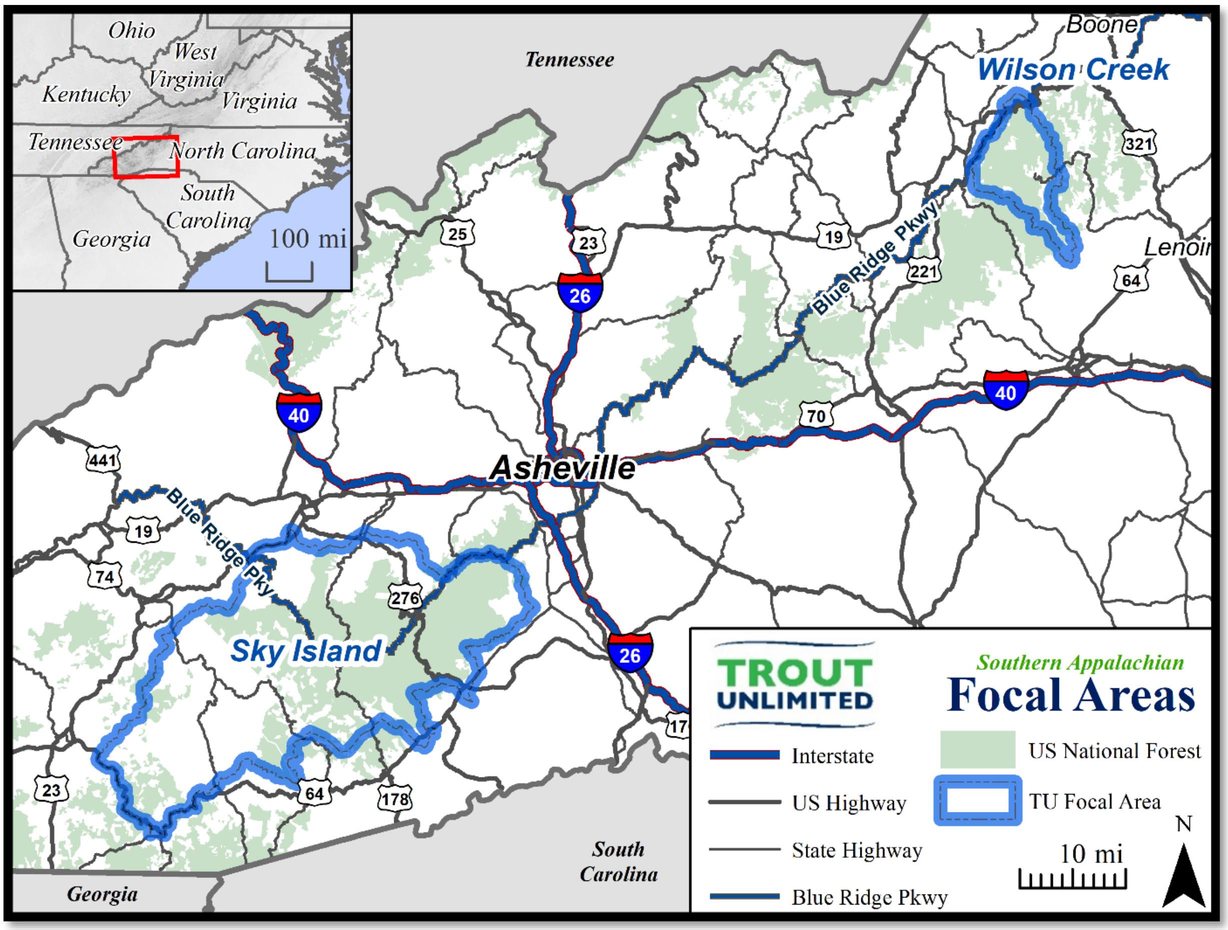

Figure 2-2. Trout Unlimited focal areas in Western North Carolina

Wilson Creek. Wilson Creek is a US Forest Service-designated Wild and Scenic River (HUC 030501010504) located in Avery and Caldwell counties at the eastern edge of the mountain region in North Carolina (Figure 2-3). It originates from headwaters on the south slope of Grandfather Mountain and culminates at its confluence with Johns River in the town of Johns River, north of Morganton (United States Department of Agriculture 2005). Approximately 74 square kilometers, the Wilson Creek watershed is primarily composed of Forest Service land and is host to abundant coldwater streams as well as an extensive forest road network.

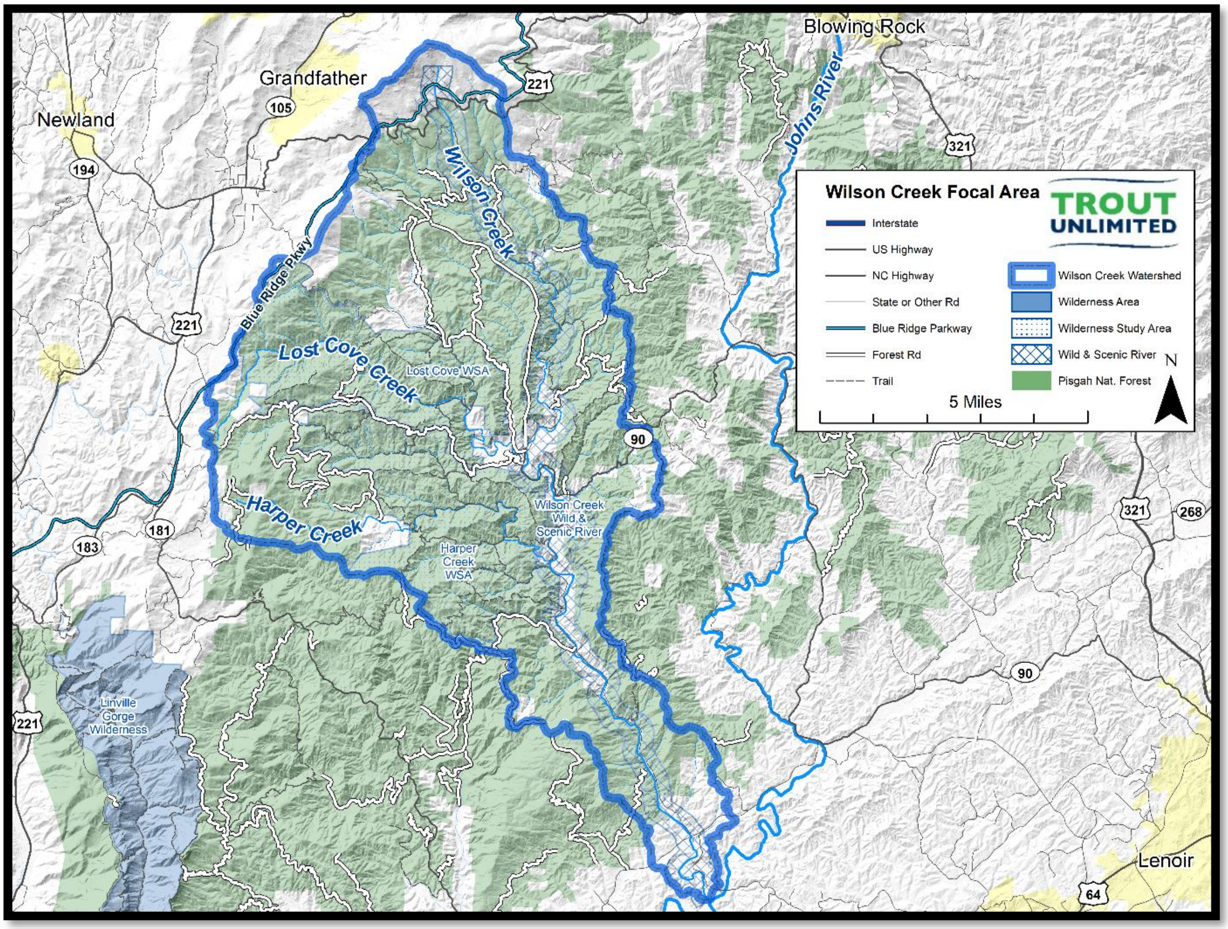

Figure 2-3. Wilson Creek watershed, including Wilson Creek Wild & Scenic River, Lost Cove Creek Wilderness Study Area, and Harper Creek Wilderness Study Area

Sky Island. "Sky Island" refers to an area of approximately 1550 square kilometers southwest of Asheville, NC (Figure 2-4). The area is comprised of several coldwater stream systems located along and near the Blue Ridge Parkway and generally ranging from 1,000 meters to almost 2,000 meters in elevation. Sky Island contains the headwaters and upper sections of several watersheds, including the North & South Forks of Mills River (HUC 0601010504), the East & West Forks of the Pigeon River (HUC 0601010601), the French Broad River (HUC 06010105) (including Catheys Creek, HUC 060101050104), and the Tuckasegee River (HUC 06010203) (Figure 2-4).

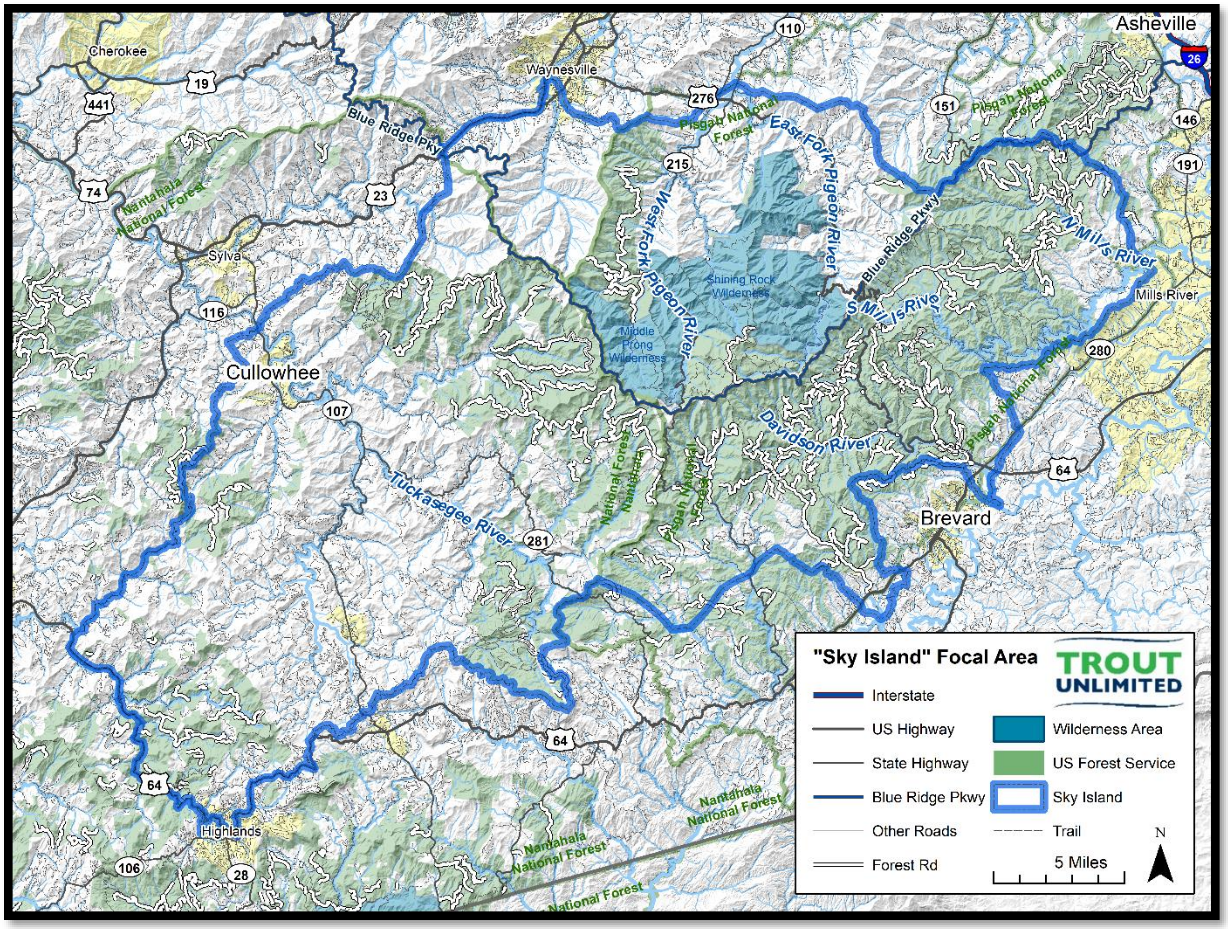

Figure 2-4. Sky Island focal area, including portions of the upper watersheds of the North & South Mills Rivers, East & West Pigeon River, French Broad River, and Tuckasegee River

Community Recruitment and Training Process

To effectively train and engage concerned community members to examine and report erosion on unsealed forest roads, three main processes were executed: the survey methods were redeveloped, the community science program was implemented, and the resulting data were analyzed (Figure 2-5).

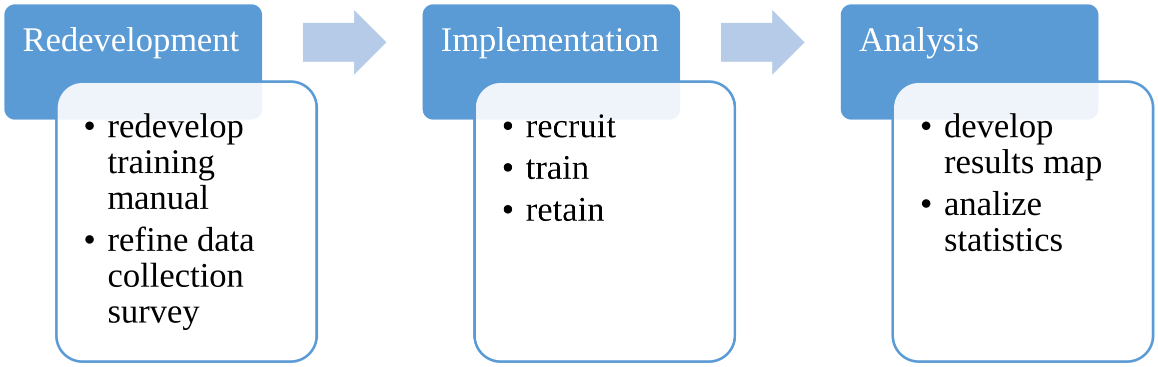

Figure 2-5. Tasks performed for Study I

The North Carolina Council of Trout Unlimited (NCTU) Communications Chair as well as Presidents of individual TU Chapters in or near the two focal areas shared sedimentation survey training opportunities with TU members. The Drift, a quarterly magazine published by NCTU, included a story on the Community Science Program – called the Citizen Science Program then – in the Winter 2019 volume (Appendix B). In addition, the Coldwater Conservation Manager for the Southern Appalachians attended several local chapter meetings to discuss the project to recruit volunteers and donors.

Recruitment from outside the TU roster was also conducted. Information about the project and training dates was disseminated through partner organizations and other associated NGO’s, such as Wild South, Haywood Waterways Association, Mills River Partnership, American Rivers, A Clean Wilson Creek, and others. An article about Western NC fisheries conservation in June 2019, helped garner support for the TU Community Science Project (Chávez 2019). Additionally, social media, such as Facebook and VolunteerMatch.com, as well as NGO collaboratives, such as the Tuckasegee Vision Group and the Grandfather District Volunteer listservs, were used to disseminate information to potential volunteers.

Before commencing data collection, interested members of the community were asked to make a volunteer commitment consisting of attendance at one half-day training to learn the sedimentation survey process followed by two or three full field data collection days, with additional field collection encouraged and supported. Volunteers were not required to be TU members or anglers; any interested parties over the age of 16 were encouraged to participate.

Interested and able volunteers were contacted personally to schedule training. Training locations, days, and times varied to accommodate the majority of interested volunteers. Specific training sites were chosen based on several criteria: located within one of the two focal areas; located on USFS land; located along a coldwater stream of interest to Trout Unlimited; ample, free parking and access to a Forest Service road and a Forest Service trail; location was not previously surveyed or not completely surveyed. These criteria ensured that data collected during the training sessions were useful to the project, rather than simply an exercise.

Training consisted of two phases: 1) project and app information and 2) field training. In the first phase, volunteers were provided with the Trout Unlimited, Pisgah-Nantahala National Forest and North Carolina Wildlife Resources Commission *Mobile App Reference Guide for Community Science Sedimentation Surveys on Trails & Roads* (Appendix A), hereinafter referred to as the Sedimentation Survey Manual. This manual provides instructions on how to install *Survey123* and connect to the *Western NC Trail/Road Sedimentation Survey v2* on a mobile device and provides instruction and examples of how to fill out each question on the form. Volunteers were encouraged to connect a phone or other device to the Survey123 form and review the Sedimentation Survey Manual prior to field training. A bound copy of the manual was provided to volunteers at the beginning of each field training.

Field Training

Upon arrival at the training site, volunteers were greeted and the broad goals of the project were presented and discussed to foster a deeper sense of involvement in the project. Safety was discussed; volunteers were encouraged to work in groups after the training, warned of various hazards associated with outdoor recreation (i.e., bees, snakes, poison ivy, hunters, adverse weather conditions, etc.), and discouraged from putting themselves in danger in the name of data acquisition. Additionally, since much of the survey work was completed on forest roads open to public traffic, volunteers were reminded to be conscious of traffic and were provided safety vests which they were encouraged to use during all surveys.

The field training itself was a hands-on exercise that consisted of surveying a National Forest road as a group. As the group traveled along the road, great emphasis was made on all observations that helped to determine water flow during rainfall events— the mantra, “think like a drop of water,” was emphasized frequently throughout the day. At the first drainage feature, each survey question was discussed in detail, along with the best probable choice for this particular case. With each subsequent drainage feature, volunteers were increasingly encouraged to evaluate the feature on their own through group discussion without the trainer. After approximately three hours of forest road surveying, volunteers spent approximately two additional hours surveying a National Forest trail. Because of the similarity between forest road and trail drainage features, training progressed quickly on the trail, focusing generally on differences in the type and scale of drainage features.

Again, in-depth group discussion at each drainage feature was encouraged and utilized as a tool to increase understanding and buy-in for the project as well as influence the group dynamics towards cohesion. The concept that there are no ‘textbook’ drainage features – and not every drainage feature has a single or perfect answer – was stressed, and volunteers were trained to recognize this and to choose the best available option. Many of the questions included an ‘other:’ category with the option to write a brief description, however the use of this was discouraged for the sake of data cohesiveness unless the feature truly did not fit another option.

Trainings typically lasted between five and six hours, including lunch and discussion. Upon conclusion of the training, snacks, cold drinks, and gratitude were offered to volunteers upon their return to the parking area. Questions were encouraged, discussed, and answered, where possible. The importance of utilizing their new skillset to benefit public lands was impressed upon volunteers, along with reminders that their data would help drive management decisions within the National Forest in North Carolina. Volunteers were asked to commit to at least two or three full days of sedimentation surveying over the course of a year and were encouraged to spend more time if desired.

Post-training Volunteer Retainment

One or two days following the field training, a thank you email was sent to all attending volunteers. In addition to gratitude, this email contained a map packet detailing roads and trails designated as high-priority for sedimentation surveying (See Appendix C for an example) as well as a link to an ArcGIS Online web mapping application described in the next section. This web map displayed focal areas, priority roads and trails, and an accumulation of all data collected thus far. To avoid duplication, volunteers were asked to either claim a road or trail that they planned to survey or to contact the volunteer coordinator to be assigned a road or trail.

Additionally, weekly emails were sent to all trained volunteers thanking all who participated in sedimentation surveys and updating the needs list of priority trails and roads. Personal communication was required of volunteers after surveying so that their hours spent surveying and travelling to survey locations could be recorded for the grant stakeholders. Questions by email, text, or call were always encouraged and occasional TU volunteer appreciation dinners were hosted in various locations near the focal areas.

Data Dissemination and Display

A web mapping application was created to display the contributed data for volunteers and stakeholders (arcg.is/1WfWLC). Boundaries for each of the focal areas were added to a web map, along with boundaries for USFS-owned land and paths for USFS forest roads and USFS trails. Additional layers on this map included hydrologic unit code '12' (HUC 12) level streams within each focal area and North Carolina state and applicable county roads.

Secondary layers for both USFS roads and USFS trails were added to the web map and, using a definition query, specific roads and trails were selected manually as 'Priority Roads/Trails.' These were symbolized red, thick, and somewhat transparent, and set behind the other road and trail layers to highlight areas where sedimentation surveys were of increased interest. These roads were selected based on their proximity to the stream system and supposed traffic and were given equal weight within the app.

Data received through Survey123 submissions uploaded automatically into an ArcGIS Online layer, which was included in the web map. Drainage features displayed as individual points and were symbolized by the erosion severity of the contributing prism – green for stable to red for gully erosion. This layer updates automatically when new data are submitted.

The web map was shared as a web mapping application via ArcGIS Online. The app was built within ESRI's Web App Builder platform, and included the web map and legend, information on the sedimentation survey, and tools to measure, share, and export printable views of the map at various scales. These automated printable exports were designed to be used as field maps by volunteers if desired.

Statistical analyses. Data gathered through the sedimentation surveys were examined statistically via the IBM Statistical Product and Service Solutions Statistics 26 (SPSS) computer application. A series of forward-stepwise logistic regression models were developed to test which variables affect whether road or trail sediment makes it into the stream, a 'yes/no' category within the sedimentation survey. Parameters examined included 'drainage type,' 'surfacing,' 'prism shape,' 'prism condition,' 'length of erosion on prism,' and 'sediment travel distance.' Three models were developed: a lumped model using data collected for both sites, a Sky Island model, and a Wilson Creek model. For each model, all data points were used for model development because the intent of the process was to identify variables associated with sediment transport to the stream (rather than develop a true prediction model which would require calibration and validation).

Additionally, Pearson Chi-Squared Tests were performed via SPSS to test the significance of the relationship between 'drainage type' and 'prism condition' to investigate whether different drainage types were corelated with increased erosion levels on the roadway. Three tests were performed: one for each site, Sky Island and Wilson Creek, and one using all data. To address 'drainage type' and 'prism condition' pairings with counts too low for statistical adequacy, variables were removed from the test until greater than 80% of cells had an expected count greater than 5, and the minimum expected cell count was greater than 1.

Results

Results from the Western NC Sedimentation Survey continue to be received because the project is ongoing. The NC Clean Water Management Trust Fund is still in effect and work with the USFS and other organizations continues. TU plans to continue its community science program as long as funding remains. Results will therefore be based on a snapshot of data received between May 16, 2019, and April 23, 2020.

Volunteer Recruitment and Training Results

Recruitment of volunteers is essential to any community science program. Thirty-five volunteer sedimentation surveyors were trained across both focal areas, through eleven training events (Table 2-1). An additional two untrained volunteers logged survey hours assisting trained volunteers. Some volunteers logged hours in both focal areas, but most completed surveys within one of the two focal areas: Wilson Creek or Sky Island.

Table 2-1. Western NC Sedimentation Survey Volunteer Statistics

		Wilson Creek	Sky Island	**Total**
	Training events	4	7	**11**
	Volunteers trained	8	27	**35**
	Training hours	38	124	**162**
Post-training volunteer	1 survey day completed	2	2	**4 volunteers**
	2 survey days completed	0	3	**3 volunteers**
	3+ survey days completed	2	1	**3 volunteers**
	Total survey hours completed	79	47	**126 hours**

Wilson Creek. Eight volunteers were trained at four training events located within the Wilson Creek focal area, for a total of 38 training hours logged (Table 2-1). A total of 79 post-training survey hours were logged by four volunteers, and two volunteers completed more than two survey days (Table 2-1). The top performer of the Wilson Creek volunteers logged 52 hours over eight field days.

Sky Island. Twenty-seven volunteers were trained at seven training events at the Sky Island focal area, for a total of 124 training hours logged (Table 2-1). Fourteen of these volunteers were recruited by a partner organization and trained at a custom training event created for them. A total of 47 post-training survey hours were logged by six volunteers, and four volunteers completed more than one survey day (Table 2-1). The top performer of the Sky Island volunteers logged 27 hours over the course of four field days.

Data Dissemination

The Trout Unlimited Western NC Trail/Road Sedimentation Survey web mapping application created in ArcGIS provided an interactive view of data collected by community scientists assisted with prioritization of roads and trails for which data collection was needed (Figure 2-6). This web mapping app can be viewed by visiting arcg.is/1WfWLC.

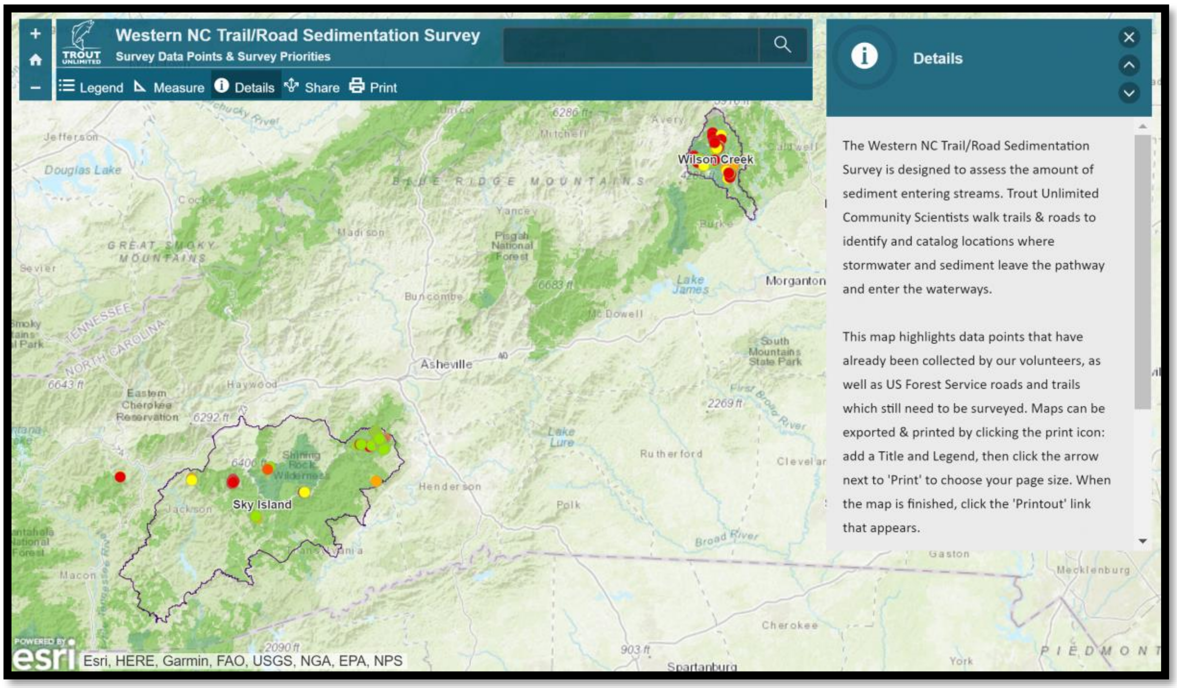

Figure 2-6. Screenshot of the *Trout Unlimited Western NC Trail/Road Sedimentation Survey: Survey Data Points & Survey Priorities*, an ArcGIS Online web mapping application to share information with volunteers and stakeholders

Users of the web mapping application browse various locations within each focal area to find forest roads and trails considered priorities for surveying (highlighted in red) and roads where surveys are complete. Additionally, the web map permits examination of individual data points, including all survey parameters and a link to the picture if one was taken (Figure 2-7).

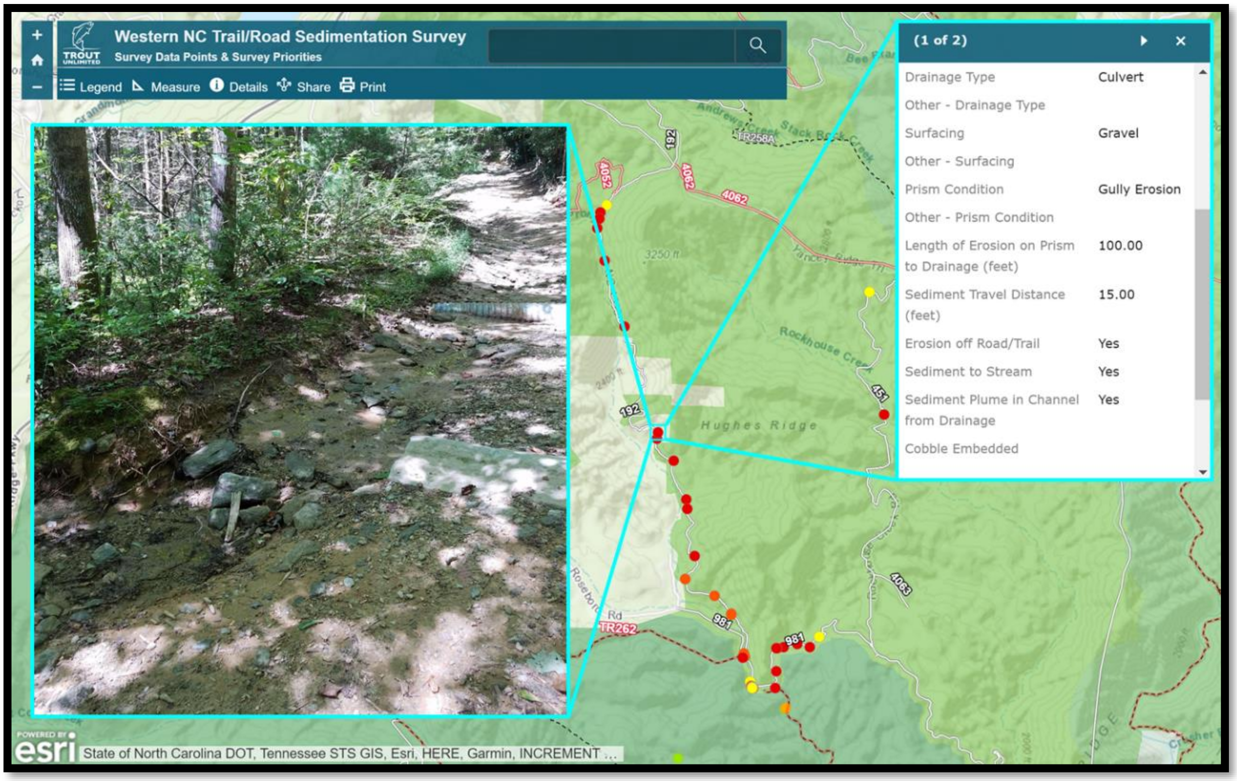

Figure 2-7. Example of a survey data point pop-up information box and picture (available by link where applicable)

Users of the web mapping application may also export maps. This feature can be useful for community science volunteers who wish to print a field map before beginning a day of sedimentation surveying, or for displaying results from the sedimentation survey (see Figures 2-8 and 2-9 for examples). Sedimentation survey results in Wilson Creek watershed are well distributed, with many of the priority roads and some of the priority trails completed or partially completed (Figure 2-8). Conversely, sedimentation surveys in Sky Island are concentrated in the Mills River area, with limited surveys completed in small hotspots in the Tuckasegee watershed (Figure 2-9).

Wilson Creek Results

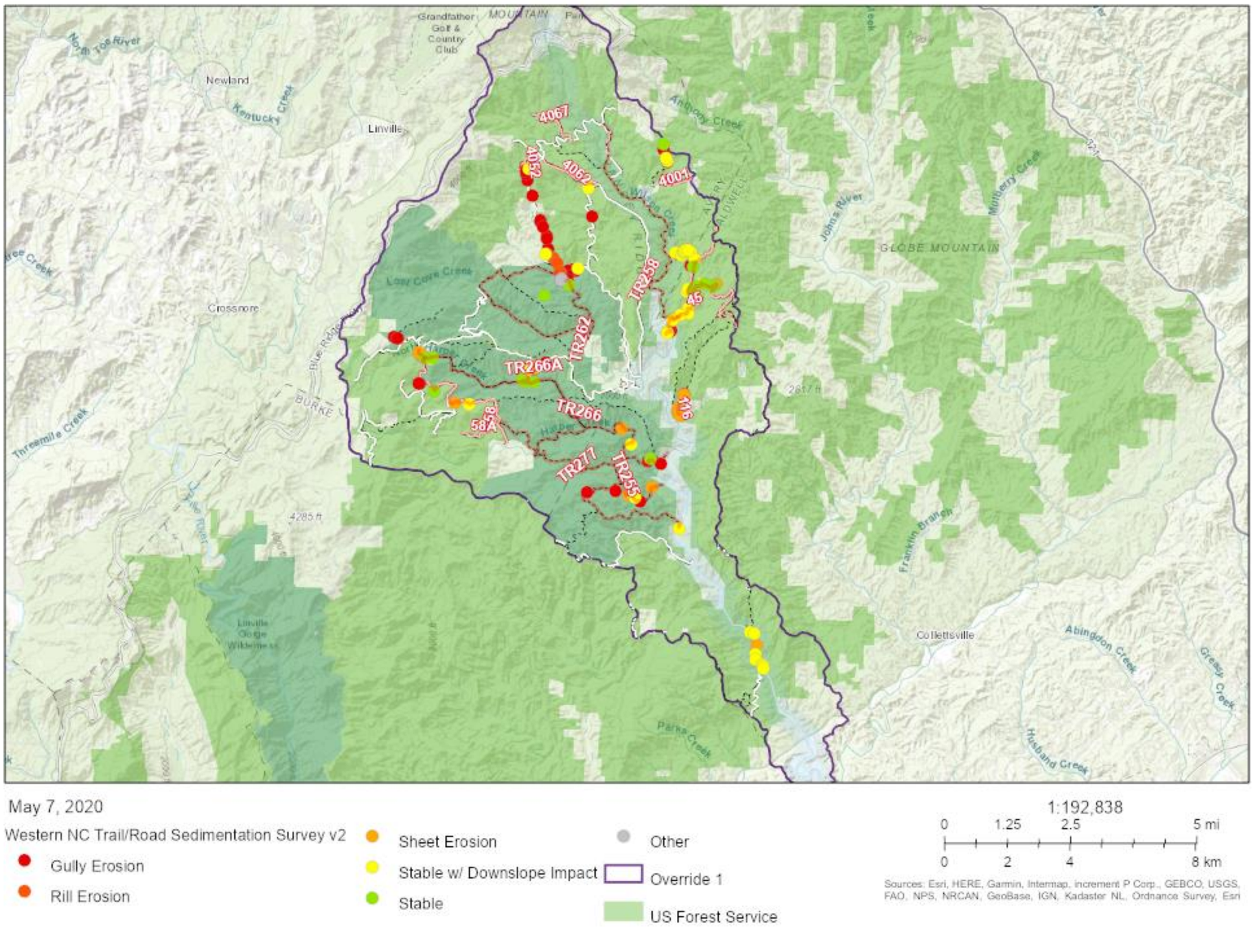

Figure 2-8. Automated map output from the Trout Unlimited Western NC Trail/Road Sedimentation Survey web mapping application showing the Wilson Creek focal area

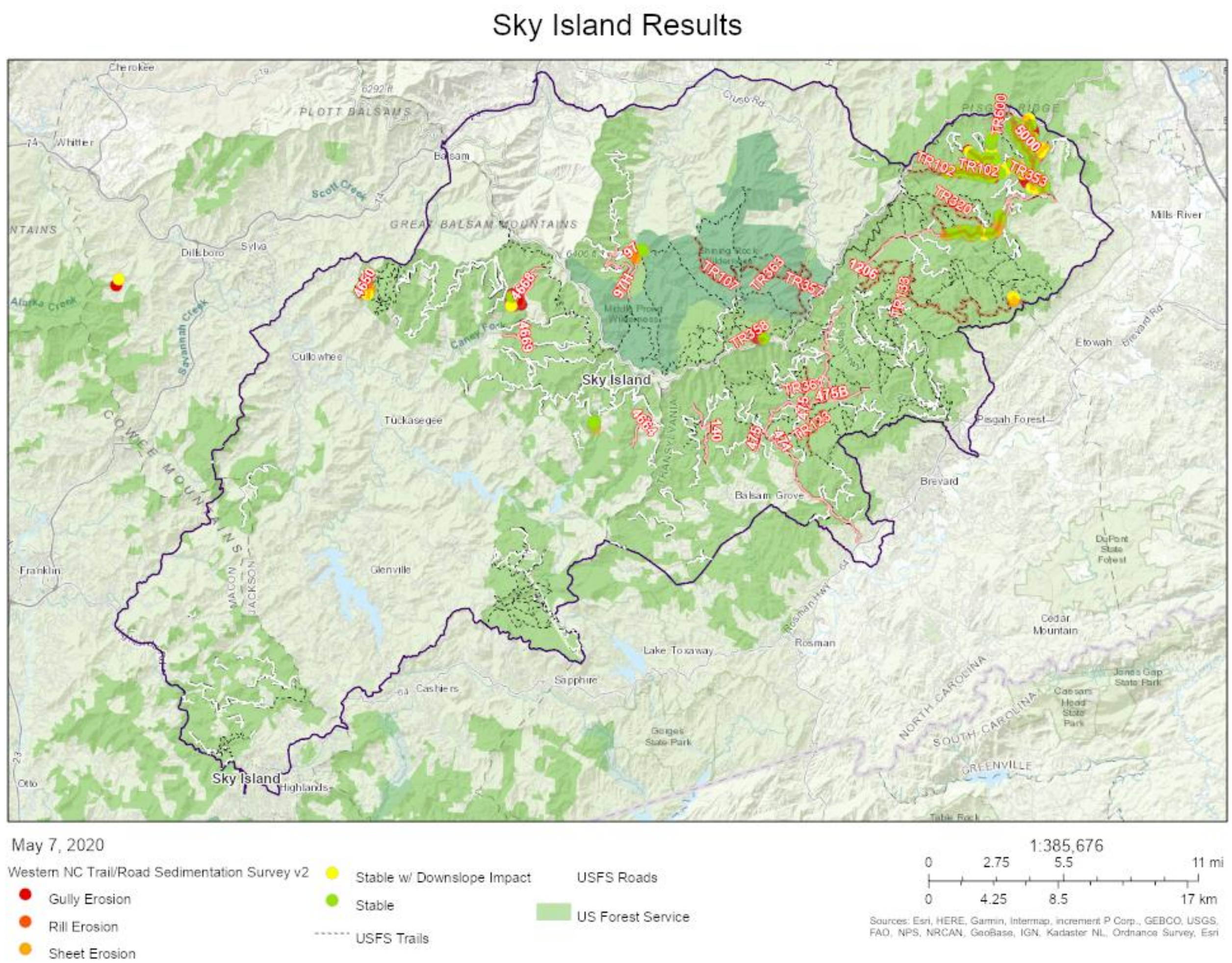

Figure 2-9. Automated map output from the Trout Unlimited Western NC Trail/Road Sedimentation Survey web mapping application showing the Sky Island focal area

Factors Influencing Stream Sedimentation

To assess which factors influenced stream sedimentation, the full dataset was assessed concurrently (referred to as the lumped data) as well as separately for each focal area. A total of 497 drainage points were located on USFS lands (Table 2-2). Of these, 286 (58%) were marked as supplying sediment to a nearby stream, with 146 (29%) creating a visible sediment plume where the sediment enters the stream (Table 2-2). Drainage features had an average sediment travel distance of 11 meters and were supplied by an average of 52 linear meters of erosion on road or trail surfaces (Table 2-2).

Table 2-2. Drainage Feature Data by Drainage Type, Collected by Community Scientists

	Drainage Type	*Total Count*	*Sediment to Stream*		*Sediment Plume*		*Average Sediment Travel (m)*	*Average Erosion Length (m)*
			Yes	*No*	*Yes*	*No*		
Wilson Creek	*stream crossing*	30	27	3	10	20	3.5	24.1
	diversion ditch	8	6	2	0	8	30.1	230.0
	rolling dip	3	0	3	0	3	1.8	7.4
	grade sag	27	22	5	10	17	16.9	86.5
	waterbar	3	3	0	2	1	4.5	81.3
	outslope	34	26	8	11	23	17.4	37.7
	culvert	27	11	16	5	22	4.4	61.5
	other	12	8	4	6	6	14.8	40.2
	Wilson Creek Totals	**144**	**103**	**41**	**44**	**100**	**11.7**	**71.1**
Sky Island	*stream crossing*	60	52	8	35	25	1.4	27.0
	diversion ditch	20	9	11	7	13	9.9	52.0
	rolling dip	21	13	8	10	11	23.3	60.1
	grade sag	44	23	21	8	36	8.7	32.9
	waterbar	31	3	28	2	29	2.7	21.4
	outslope	37	30	7	18	19	6.4	36.4
	culvert	121	40	81	11	110	4.8	58.3
	other	19	13	6	11	8	20.7	63.1
	Sky Island Totals	**353**	**183**	**170**	**102**	**251**	**9.7**	**43.9**
Totals		**497**	**286**	**211**	**146**	**351**	**11.0**	**51.6**

Wilson Creek. Within the Wilson Creek focal area, 144 drainage features were identified. Of these features, 103 (72%) visibly supplied sediment to the stream system, and 44 (31%) created a visible sediment plume where the sediment entered the stream (Table 2-2). Drainage features in Wilson Creek had an average sediment travel distance of roughly 12 meters and were supplied by roughly 71 linear meters of erosion on road or trail surfaces (Table 2-2).

The most documented drainage feature in Wilson Creek was ‘outslope,’ with 34 datapoints submitted through the survey (Table 2-2). Aside from features marked ‘waterbar’ and ‘rolling dip,’ which only had three samples each, the drainage type with the highest proportion of features supplying sediment to the stream was ‘stream crossing’ at 27 of 30 observations (90%) and the drainage type with the lowest proportion of features supplying sediment to the stream was ‘culvert’ at 11 of 27 observations (41%) (Table 2-2).

Sky Island. Within the Sky Island focal area, 353 drainage features were identified. Of these features, 183 (52%) supplied sediment to the stream system, and 102 (29%) created a visible sediment plume where the sediment entered the stream (Table 2-2). Drainage features in Sky Island had an average sediment travel distance of about 10 meters and were supplied by roughly 44 linear meters of erosion on road or trail surfaces (Table 2-2).

The most documented drainage feature in Sky Island was ‘culvert,’ with 121 data points submitted through the survey (Table 2-2). The drainage type with the highest proportion of features supplying sediment to the stream was ‘stream crossing’ at 52 of 60 observations (87%) and the drainage type with the lowest proportion of features supplying sediment to the stream was ‘waterbar’ at 3 of 31 observations (10%) (Table 2-2).

Logistic Regression Models

Using all contributed data, a lumped logistic regression model developed to predict whether sediment was transported to the stream (dichotomous data) returned a Nagelkerke R^2 value of 0.364. The model retained ten significant variables, including length of erosion on prism (continuous data), six drainage type variables (categorical data), two prism condition variables (categorical data), and a constant (Table 2-3). The lumped model accurately predicted whether sediment was transported to the stream in 73.8% of cases and was more likely to return false positive than false negative results (Table 2-3).

The Wilson Creek logistic regression model to predict whether sediment was transported to the stream failed to return any significant factors. The Sky Island logistic regression model to predict sediment transport to stream returned a Nagelkerke R^2 value of 0.373. The model correctly predicted sediment transport to the stream in 74.2% of cases, returning more false negatives than false positives (Table 2-3). This model returned 11 significant variables, including length of erosion on prism (continuous data), seven drainage type variables (categorical data), two prism condition variables (categorical data), and a constant (Table 2-3).

Table 2-3. Logistic Regression Models Predicting Sediment Contribution to the Stream Network

	Nagelkerke R^2 value			Predicted sediment to stream: no	yes	% correct	Significant Variables[1]		p-value	exponent
All Drainage Features	0.364	Observed sediment to stream	no	133	78	63.0%	*length of erosion on prism*		0.023	1.002
							Drainage Type	*stream_crossing*	0.000	39.701
								rolling_dip	0.013	4.839
								grade_sag	0.000	7.835
			yes	52	234	81.8%		*outslope*	0.000	14.512
								culvert	0.020	3.291
								other	0.000	10.106
			Overall percentage			73.8%	Prism Cond.	*rill erosion*	0.030	0.377
								stable	0.000	0.242
							constant		0.020	0.298
Sky Island	0.373	Observed sediment to stream	no	130	40	76.5%	*length of erosion on prism*		0.043	1.008
							Drainage Type	*stream_crossing*	0.000	69.101
								diversion_ditch	0.023	6.295
								rolling_dip	0.002	12.240
			yes	51	132	72.1%		*grade_sag*	0.001	10.573
								outslope	0.000	35.463
								culvert	0.017	5.021
								other	0.001	16.444
			Overall percentage			74.2%	Prism Cond.	*rill erosion*	0.020	0.265
								stable	0.000	0.224
							constant		0.014	0.184

[1]Variables provided for the model were drainage type, prism condition, surfacing, prism shape, length of erosion on prism, and sediment travel distance.

Road Erosion Severity

Of the 497 drainage features surveyed, 123 (25%) of the supplying roads or trails experienced gully erosion, 47 (9%) experienced rill erosion, 77 (16%) experienced sheet erosion, 143 (29%) were stable, and 105 (21%) were stable but with a significant impact downslope of the drainage feature (Table 2-4). A majority of drainage features marked ‘diversion ditch’ or ‘rolling dip’ experienced ‘gully erosion,’ a majority of ‘outslope’ drainage features were ‘stable with downslope impact,’ and a majority of ‘culverts’ were ‘stable’ (Table 2-4). A Pearson Chi-Squared test indicates a significant relationship between ‘drainage type’ and ‘prism condition’ at p = 0.000, with 14.3% of cells with an expected count of less than 5 and a minimum expected count of 2.28.

Wilson Creek. Of the 144 sections of road or trail supplying the drainage features surveyed in Wilson Creek, 45 (31%) experienced ‘gully erosion,’ 10 (7%) experienced ‘rill erosion,’ 28 (19%) experienced ‘sheet erosion,’ 17 (12%) were ‘stable,’ and 42 (29%) were ‘stable w/ downslope impact’ (Table 2-4). A majority of drainage features marked ‘rolling dip,’ ‘grade sag,’ or ‘waterbar’ experienced ‘gully erosion,’ a majority of ‘outslope’ drainage features were ‘stable with downslope impact,’ and a majority of feature marked ‘culvert’ were either ‘stable’ or ‘stable with downslope impact’ (Table 2-4). A Pearson Chi-Squared test indicated no significant relationship between ‘drainage type’ and ‘prism condition.’

Table 2-4. Crosstabulation of Erosion Level by Drainage Type

	Drainage Type	gully erosion		rill erosion		sheet erosion		stable		stable w/ downslope impact	
Wilson Creek	*stream crossing*	6	20%	1	3%	8	27%	5	17%	10	33%
	diversion ditch	2	25%	4	50%	1	13%	0	0%	1	13%
	rolling dip	3	100%	0	0%	0	0%	0	0%	0	0%
	grade sag	11	44%	3	12%	5	20%	1	4%	5	20%
	waterbar	3	100%	0	0%	0	0%	0	0%	0	0%
	outslope	10	29%	0	0%	9	26%	0	0%	15	44%
	culvert	6	22%	0	0%	4	15%	8	30%	9	33%
	other	4	33%	2	17%	1	8%	3	25%	2	17%
	Total Prism Condition	**45**		**10**		**28**		**17**		**42**	
Sky Island	*stream crossing*	22	37%	0	0%	4	7%	19	32%	15	25%
	diversion ditch	12	60%	1	5%	1	5%	4	20%	2	10%
	rolling dip	12	57%	5	24%	1	5%	1	5%	2	10%
	grade sag	8	18%	1	2%	3	7%	19	43%	13	30%
	waterbar	2	6%	14	45%	8	26%	2	6%	5	16%
	outslope	11	30%	2	5%	0	0%	8	22%	16	43%
	culvert	6	5%	13	11%	25	21%	69	57%	8	7%
	other	5	26%	1	5%	7	37%	4	21%	2	11%
	Total Prism Condition	**78**		**37**		**49**		**126**		**63**	
Totals		**123**		**47**		**77**		**143**		**105**	

[1]Results include a count of the number of features and the percent within drainage type for each erosion level.

Sky Island. Of the 353 sections of road or trail supplying the drainage features surveyed in Sky Island, 78 (22%) experienced 'gully erosion,' 37 (10%) experienced 'rill erosion,' 49 (14%) experienced 'sheet erosion,' 126 (36%) were 'stable,' and 63 (18%) were 'stable w/ downslope impact' (Table 2-4). A majority of drainage features marked 'diversion ditch' or 'rolling dip' experienced 'gully erosion,' a majority marked 'waterbar' experienced 'sheet erosion' or 'rill erosion,' a majority marked 'gradesag' or 'outslope' were 'stable' or 'stable w/ downslope impact,' and a majority marked 'culvert' were 'stable' (Table 2-4). A Pearson Chi-Squared test indicates a significant relationship between 'drainage type' and 'prism condition' at $p = 0.000$, with 16.0% of cells with an expected count of less than 5 and a minimum expected count of 3.17.

Discussion

Volunteers

Volunteer recruitment and retainment is the first and perhaps most important piece of a community science initiative and may be the greatest challenge faced by community science programs (Conrad and Hilchey 2011). This was a challenge for the Western NC Sedimentation Survey.

Recruitment. Of the seven training events held in Sky Island and the four training events held in Wilson Creek, both the median and mode for the number of volunteers trained was two. Sky Island had a much higher mean – four volunteers trained as opposed to two and a quarter in Wilson Creek – due to a single training event with fifteen volunteers present. The great success of this training event was due entirely to help from Haywood Waterways Association, another water quality concerned non-profit, non-governmental organization (NGO) in Western NC, who requested a training event be set up for a group of frequent volunteers who expressed interest in conducting sedimentation surveys.

The best recruitment outcomes came from advertisement through other similar NGO's. These organizations tended to each have their own group of dedicated individuals interested in environmental volunteerism. Since the relationships were already fostered, a forwarded email from trusted organizations promoting the TU community science program held much more weight than a simple mass email sent to various listservs. Almost two thirds of the total volunteers were recruited through various other NGO's, including but not limited to: Haywood Waterways Association, Mills River Partnership, American Rivers, and Wild South.

Recruitment from within the TU ranks was moderate, accounting for nine of the thirty-five trained volunteers. However, this may have had a better outcome if training sessions were held in the spring or fall as TU meetings do not continue through summer months. This resulted in a heavy reliance on emailing individuals who had expressed interest from earlier advertisement, sometimes more than six months prior. Understandably, some volunteers expressed irritation when they had not heard back for several months after indicating interest, and many never renewed communication. The communication delay was due to down time between initial release and renewal of the program in May of 2019, however, it is recommended that volunteers be contacted within days of expressing interest rather than months.

A Citizen Times article in June 2019 on Western NC fisheries and coldwater conservation garnered some interest in the community science program (Chávez 2019). Six people who read the article reached out to express interest in participating in sedimentation surveys, and three of those ultimately were trained. This, coupled with TU members who learned about the program from The Drift article in January of 2019, accounted for approximately 15% of the volunteers who were ultimately trained.

Invitations to training events posted on Facebook and VolunteerMatch provided no positive outcome. Often, several people marked themselves interested but did not follow through by attending the event. The "scroll-and-click" nature of Facebook seemed to garner a vague, superficial interest but no true commitment. One might expect VolunteerMatch to have a higher impressionability rate among those who saw the posts, as the site is focused on volunteer opportunities, however, the site's traffic is much smaller than Facebook. Furthermore, TU did not have a paid membership which, while not required to post an event, would have provided better exposure to potential volunteers.

Retainment. Once recruited and trained, volunteers agreed to conduct sedimentation surveys on their own (or, preferably, with a partner). The informal agreement between TU and its volunteers was for volunteers to conduct two or three sedimentation surveys on their own time after being trained. Many volunteers, however, were unable to follow through. Of all the volunteers trained, twenty-nine percent followed up with at least one day of surveying, seventeen percent followed up with at least two days, and only nine percent followed up with three or more days of surveying. In the future, these rates may be improved by including follow-up phone calls in addition to the emails, encouraging volunteers to schedule a survey day at the end of the training, or offering TU swag after a certain number of survey hours were completed.

Differences in volunteer participation between the sites were due to individual volunteers rather than differences in communication or training techniques, because communication and training were identical across the two sites. Despite more than three times as many volunteers trained in Sky Island, Wilson Creek volunteers logged almost twice as many post-training survey hours. This was mainly due to one extremely dedicated volunteer who, over the course of eight days of sedimentation surveying, logged sixty-six percent of the total survey hours in Wilson Creek. This specific volunteer was part of a naturalist program and a write-up of TU's project goals enabled the volunteer to count the sedimentation surveys towards community service hours for the naturalist program.

Additionally, two volunteers in Sky Island were students at Western Carolina University who used sedimentation surveys as a final project in an aquatic ecosystems course. They accounted for half of the volunteers in Sky Island who completed at least two days of sedimentation surveys. Of the thirty-five total trained volunteers, these three logged more than half the total post-training survey hours. This unsurprisingly suggests that finding volunteers who can use survey hours for other requirements will lead to a far greater recurrence rate of sedimentation surveys. This could be accomplished by targeting recruitment efforts to people in charge of programs such as the Master Naturalist program or college professors and clubs which may have goals or topics aligning with those of this program.

The effectiveness of the web mapping application as a tool for volunteers is unknown. This map allows sedimentation survey participants to browse data that they have submitted and also explore areas on the map that are both priority areas and lack data points. However, weekly emails sent to volunteers in each group also included a list of priority roads and trails which volunteers may have used to decide on sedimentation survey locations. Data analytics for the web mapping application indicate 560 total views, but no data were collected on the number of map downloads or number of individual users. It is possible that the web application is useful as a communication tool and as a project management tool for TU more so than its utility as a decision tool for individual volunteers.

Sedimentation Survey Results

Wilson Creek. Surveyed roads and trails in Wilson Creek were evenly distributed across the watershed. Not surprisingly, the drainage type ‘stream crossing’ was most common to supply sediment to the stream, visibly delivering sediment 90% of the time. However, one could reasonably expect every stream crossing to supply sediment to the stream. Ground truthing and more quality control may be needed to assess stream crossings marked as not supplying sediment to the streams.

Culverts were the least common drainage feature to supply sediment to the stream. ‘Culvert’ drainage features include a prism inslope towards a ditch on the upslope side of the road which drains a section of the road to the downslope side by means of a culvert beneath the road. When properly constructed and maintained, these features leave much of their sediment in the ditch and are drained to an area that can support dispersion through the underbrush.

Areas in Wilson Creek using ditches and culverts as the main drainage method are most likely to be supplied by roads with a prism condition of ‘stable’ or ‘stable w/ downslope impact,’ occurring 30% and 33% of the time, respectively. Since this method of drainage utilizes an inslope to allow water to quickly leave the road surface, instead travelling in a ditch before draining through the culvert, water on the prism surface often does not get the chance to acquire the energy needed to cause serious erosion. However, culverts must be properly maintained to effectively disperse draining water. When dropped from a height, water leaves the culvert with an excess of energy which can cause a significant downslope impact along the flow path.

Sky Island. Surveyed roads and trails in Sky Island were fairly localized in the focal area. The vast majority of sedimentation surveys in Sky Island were completed in the Mills River area, in the northeast corner of the focal area. This was by design as the initial focus was on the Mills River area and volunteers were directed to this priority area in weekly emails. The plan was to move onto the Davidson River and Cathys Creek areas (center-east) in the spring of 2020, with specific volunteers focusing on the few priorities in the Pigeon and the Tuckasegee watersheds. Disruptions to the fulfillment of this goal were exacerbated by effects of the COVID-19 pandemic, beginning in late 2019.

The most common drainage features to deliver sediment to the stream were ‘stream crossing’ in Sky Island – like Wilson Creek, this rate was also around 90%. The drainage features type least likely to supply sediment to the stream were ‘waterbar.’ Waterbars are primarily trail features and, when properly constructed and maintained, function extremely well at shifting water off the trail before it can erode much trail surface. Also, because of native surfacing and the fact that most trails were limited to foot traffic, trail drainage features were much less likely to be the source of significant sedimentation. The least likely road drainage features to deliver sediment to Sky Island streams were ‘culvert.’

Areas in Sky Island using ditches and culverts as the main drainage method are most likely to be supplied by roads with a prism condition of ‘stable,’ at 57% of the time. The lack of a large amount of ‘stable w/ downslope impact’ may have to do with the fact that most culverts surveyed in Sky Island were located on a popular and well maintained road (FS-5000, Wash Creek Rd), or it may be related to judgement differences between community scientists. Roads and trails drained by ‘diversion ditches’ and ‘rolling dips’ were most likely to be experiencing ‘gully erosion,’ at 60% and 57% of the time, respectively. Both of these features require water to travel along the prism for some amount of distance before draining, allowing the increasing water energy to erode the prism surface.

Several variables were retained in the Sky Island logistic regression model. The odds of sediment reaching the stream were increased by 1.002 for each additional meter of erosion on the prism. Similarly, the presence of seven drainage types were associated with increased odds of sediment reaching the stream, ranging from 5.021 (‘culvert’) to 69.101 (‘stream crossing’). The extremely high odds ratio of ‘stream crossing’ – about twice as high as the second highest, ‘outslope’ – fits with the assertion that stream crossings contribute more sediment to streams than any other land management activity (Orndorff 2017). Two prism conditions were associated with reduced odds of sediment reaching the stream: the presence of rill erosion (odds ratio of

0.265) and stable prism (odd ratio of 0.224). The Sky Island model shows a much narrower and even spread of false negatives and false positives.

Differences Between Study Areas

Differences between drainage feature data from each of the two focal areas can partially be explained by geographic and physiographic differences. Wilson Creek is comprised of a single, full watershed with an area of 178 square kilometers. An extremely popular day use area, the lower section of the watershed is a gorge prone to flash-flooding events that result in road and trail washouts and excess sedimentation. The upper reaches of the watershed are used more sparsely, typically by hikers and anglers in search of swimming and fishing holes.

Sky Island has a much larger area (1,552 square kilometers) consisting of the headwaters of several distinct watersheds. The most trafficked of these watersheds are the Mills, Davidson, and the far upper Pigeon River watersheds, which are all popular outdoor recreation destinations for residents of nearby Asheville, NC. USFS lands in the Pigeon are composed of mostly wilderness area and see the most streamside traffic along the footpaths in the Graveyard Fields area and the Shining Creek area. The Tuckasegee watershed comprises 40% of the area of Sky Island but contains much less USFS lands than the other watersheds.

The average length of prism erosion contributing to each drainage point is much higher in Wilson Creek than it is in Sky Island, at 71.1 and 43.9 meters, respectively. This matches the distribution of survey points on specific roads: a greater frequency of drainage features was located on each surveyed road in Sky Island than in Wilson Creek.

This trend may be related to traffic and funding. Wash Creek Rd (FS-5000) is a popular route to various parking areas in the Mills River area, just outside Asheville, NC. The road is well-graded and maintained and is drained mainly by culverts between 30 to 150 meters apart.

Culverts on this road account for almost 20% of the drainage features collected in Sky Island. In contrast, Old House Gap Rd (FS-192) in Wilson Creek is open to traffic but is unmaintained and requires a high-clearance vehicle to traverse. Because it is unmaintained, this road is extremely gullied and, at some survey points, the length of erosion on the prism is in excess of 500 meters.

The full model likely shows similar significant variables due to the greater number of data points in Sky Island than in Wilson Creek. The drainage feature 'diversion ditch' was the only drainage feature included in the Sky Island logistic regression model that was not included in the lumped model. This was likely due to differences in this feature between the two areas; only 45% of diversion ditches in Sky Island delivered sediment to the stream while 75% of diversion ditches in Wilson Creek delivered sediment to the stream.

Differences in the model results between the two areas may be explained by the distribution of located features in each area. Wilson Creek data were well distributed across the watershed and include several different roads and trails of differing erosional severity. Sky Island data were mainly contained within Mills River watershed. A popular recreation area just outside Asheville, roads and trails in Mills River are typically well-maintained, which standardized the data from Sky Island to a much greater degree than data from Wilson Creek.

Limitations and Future Research

A major limitation for this project was due to a false start in the fall of 2018 and the subsequently long interval of time before restarting the project in May of 2019. Many potential volunteers who had attended a training before the final methodology was completed declined to answer requests to get retrained with the correct methods and second version of the sedimentation Survey123 form. Additionally, the absence of TU meetings in the summer months greatly hurt training turnout. TU members should have been the easiest to recruit yet accounted for only 22% of the trained volunteers; those TU members who did train, however, were more likely to conduct sedimentation surveys after training. Presentations at TU chapter meetings could have greatly bolstered interest in the community science program and, subsequently, the number of volunteers and the amount of data collected.

The COVID-19 pandemic also presented a major limitation for this project; training sessions due to start in late-March 2020 were cancelled. Furthermore, National Forest road and trail closures, along with a general feeling of anxiety about going out, kept some volunteers from performing surveys once springtime came around (Jeffery Wright, personal communication).

Another limitation for any community science project – or any science where data are collected via multiple sources – lies in data consistency (Gardiner et al 2012; Robson 2012). Despite attending similar training events, each community scientist may describe and interpret sites differently. Perhaps the most common example of this lies in the difference between 'lumpers' and 'splitters,' who tend to combine details into a smaller number of larger picture examples or separate details into a larger number of more specific examples, respectively. To address this difference, it is recommended that more than one community scientist survey each road and trail at different times. This can act as built-in quality control where needs for ground-truthing can be made apparent.

Conclusion

Community science can be an excellent tool to educate and involve the general public directly in the issues that affect them and collect more data than may be possible for small organizations. The Trout Unlimited Community Science Western NC Trail/Road Sedimentation Survey was successful in collecting data on road and trail erosion within its areas of focus; a number of small modifications can be implemented to increase the effectiveness of this and similar programs.

Mass emails were ineffective and should not be relied upon. Instead, emails to established volunteers can be an effective communication method but should be subsidized with phone calls directly to individual volunteers. Development of a personal relationship between the coordinator and the community scientists can help the volunteers feel more connected to the project and therefore be more likely to collect more data. The best recruitment results came from direct requests to other organizations with similar goals to share the opportunity with their established volunteers. In-person networking is recommended to spread knowledge of, and garner interest in, the project. Additionally, a focus on recruitment of community scientists who can use sedimentation survey volunteer hours to meet another requirement is recommended to increase contribution and retention rates.

To help explain differences in the data between sites and between volunteers, a thorough quality control – ideally containing a certain amount of ground truthing – is needed. Furthermore, different volunteers should be encouraged to collect data at the same sites. The coordinator can use this redundancy as a form of quality control and choose to ground truth at locations where differences between volunteers is most apparent.

This study shows a strong connection between the type of drainage and the erosion level on the contributing road or trail. It also shows that drainage type, erosion level and length of erosion associated with each drainage point affect the likelihood of sediment delivery to the waterway. Well-maintained and properly placed drainage can significantly improve conditions both on the road surface and in adjacent waterways.

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CHAPTER 3. USING COMMUNITY SCIENCE DATA IN SEDIMENT MODELS OF FOREST SERVICE ROADS IN NORTH CAROLINA, USA.

Abstract

Unpaved, or unsealed, forest roads adversely affect coldwater streams through excessive erosion and the subsequent sedimentation of adjacent waterways. To help identify areas of concern, Trout Unlimited (TU) developed a Community Science initiative to gather data on sediment sources and stream-road crossings. The contributed data were included as a calibration for the lite version of the Geomorphic Road Analysis and Inventory Package (GRAIP-Lite), a GIS-based road sediment contribution model. Three GRAIP-Lite models were developed: 1) a Basic run using only elevation and road data, 2) a Calibrated run integrating community science data, and 3) an Alternate run restricting drain points strictly to those cataloged by community scientists. The analysis found statistically significant differences between Basic and Calibrated models at one of two sites, and substantial increases in sediment delivery from the Alternate model at both sites.

Introduction

The amount of suspended sediments within freshwater systems is critical to the ecological health of aquatic ecosystems. Suspended sediments lead to aquatic habitat degradation and ultimately to aquatic organism decline (Bilotta and Brazier 2008). Unsealed forest roads impact the hydrological system through three key methods: intercepting water that would otherwise infiltrate the ground, concentrating water into a flowing channel in an adjacent ditch or on the road itself, and diverting water along the grade of the road, possibly discharging it straight into a stream (Orndorff 2017). The greater the proximity of a forest road to a stream, the more likely it is that sediment will ultimately reach the stream; stream crossings affect stream sedimentation more heavily than any other land management activity (Orndorff 2017). Water that is caught in and flows through channels (advective flows) can travel two to three times further before depositing sediment than water which is able to spread out (dispersive flows) (Orndorff 2017). The quantity of sediment reaching nearby streams can be significantly decreased through the proper management of National Forest roads; adoption of appropriate management practices can significantly increase the ecological quality of lotic habitats. These management decisions, when made appropriately, are data-driven (Black et al 2012).

Data of these type are typically collected though monitoring and/or modeling the existing environmental conditions on National Forest roads. Assessment of erosion and sediment sources can come in many forms, but can include assessment of road material, erosion levels, road prism shape, road distance drained by each drain point, visible sediment paths downslope of drain points, and visible signs of road sediments entering a stream (Hansen et al forthcoming). Educating and engaging the community to help make observations and assessments on National

Forest roads can be a useful and cost-effective way to increase the data available to decision-makers (Hansen et al forthcoming).

Community-based Monitoring

Community science, also referred to as citizen science, refers to amateur involvement in scientific programs, most often observation-based, designed specifically to incorporate contribution from non-professional scientists (Silvertown 2009). This is perhaps most common in disciplines requiring a large amount of field-based observations, particularly in the environmental and ecological sciences (Silvertown 2009). Monitoring programs that incorporate community science can be extremely useful for organizations involved in environmental monitoring and restoration, particularly where adequate funding for paid positions may not exist (Conrad and Hilchey 2011). Along with the increase of public access to mobile devices with both internet access and Global Positioning System (GPS) capabilities, this has led to a significant increase in organizations and agencies that apply technology to create a community of concerned volunteers who collect and share scientific information (Connors et al 2012; Matheson 2014; Sullivan et al 2009). Geospatially-based data collection apps such as Survey123 from the Earth Science Research Institute (ESRI) can provide an easy to use platform for community members as well as built-in databases, data visualization options, and sharing opportunities (Lamoureux and Fast 2019).

Sedimentation Modeling

While field study is an important component of road erosion and stream sedimentation assessment, models can be a useful tool to estimate conditions in a much larger area and in a less labor-intensive manner. Sediment models can incorporate field data using a series of equations to predict long-term trends or event-based erosion. Such models come in two main types: models utilizing statistical relationships based on observation and those utilizing mass and energy conservation equations to determine hydrological responses, called empirical and physics-based models, respectively (Merritt et al 2003). Popular sedimentation models include both empirical models such as WARSEM and USLE, and physics-based models such as WEPP and KINEROS2 (Fu et al 2010). Regardless of the model type, most road sedimentation models include two primary components that model 1) road surface erosion rate and 2) road sediment delivery to stream networks (Fu et al 2010).

Empirical models. The Washington Road Surface Erosion Model (WARSEM) is an empirical model that uses observed data as inputs for model parameters. These inputs include annual average rainfall, road surface materials, vegetation cover, slope, traffic and maintenance, and the contributing area for road surface, cutslope, and ditch (Dubé et al 2004). Fu et al (2009) found a reasonable correlation between modeled erosion rate and observed erosion rate, with the exception of significant model overestimations at three sites. WARSEM is traditionally a database model, while the WARSEM-derived Sedimentation Model (SEDMODL), a GIS-based alternative, uses GIS Coverage layers rather than a more modern data format such as Shapefiles or Geodatabases (Dubé et al 2004; Parsakhoo et al 2014). WARSEM outputs include average annual sediment delivery for each provided road segment and for various amounts of traffic (Dubé et al 2004). SEDMODL utilizes and provides these same inputs and metrics in a geospatial format and includes a map of erosion risk, defined as "the inherent risk of soil loss" (Parsakhoo et al 2014).

The Universal Soil Loss Equation along with Modified and Revised versions (USLE, MUSLE and RUSLE, respectively) are common empirical models developed for the examination of hillslope-erosion, specifically in agricultural settings (Renard et al 1997). These models are based on input values for rainfall erosivity, surface material erodibility, slope, area, and cover and output annual net erosion (Renard et al 1997). However, RUSLE was found by Croke and Nethery (2006) to considerably overestimate sediment yields in Australia. Furthermore, because the USLE/MUSLE/RUSLE equations are based on data collected within agricultural settings they return erosion data only and do not address delivery to the stream system, and therefore their applicability to unsealed roads is limited (Fu et al 2010).

The GIS-based, empirical model ROADMOD estimates unsealed road erosion by modeling the sediment missing from a cross-sectional area of the subject road; when the average cross-sectional missing sediment is multiplied by the length of a road segment, the total erosion from that segment is obtained (Anderson and MacDonald 1998). Total annual sediment yield for each road segment is estimated for the output of this model (Anderson and MacDonald 1998). However, ROADMOD was developed using data from only one site in the US Virgin Islands and assumes no deposition nor significant erosion other than from the road surface, and therefore may not be representative of erosive tendencies at other sites (Fu et al 2010).

STJ-EROS road submodel was developed for use on the island of St. John in the U.S. Virgin Islands. It also is a GIS-based, empirical sediment model that uses rainfall, road length, width and slope, and grading frequency as inputs (Ramos-Scharrón and MacDonald 2007). This model estimates the total annual sediment yield from each segment of road including both road surface and cutslope; STJ-EROS assumes uniformity of cutslope sediment production and silt sediment size (Ramos-Scharrón and MacDonald 2007). Both ROADMOD and STJ-EROS were compared in various locations within the U.S. Virgin Islands by Ramos-Scharrón and MacDonald, who found STJ-EROS predicted sediment delivery values closer to observed measurements (Ramos-Scharrón and MacDonald 2007).

Physics-based models. The Water Erosion Prediction Project (WEPP) is an annual average, physics-based sediment delivery model for small catchment scale prediction of annual soil loss and sediment yields (Flanagan and Nearing 1995). Like USLE, it was originally developed for use in agricultural areas, however WEPP can be altered to integrate various road-specific parameters such as road surface, cutslope, ditch, fillslope, and lower hillslope; this has been done by the USFS Rocky Mountain Research Station and is available as a web-based interface, WEPP:Road (Elliot et al 1999). Despite its origin of development in the US, WEPP:Road has been successfully applied to multiple erosion studies in Australia (Forsyth et al 2006; Croke and Nethery, 2006). However, as a physics-based model WEPP:Road requires a substantial amount of estimation and information, such as climate, soil texture, gravel addition, road topography, drain spacing, road design, surface condition, and ditch condition, in order to accurately predict sediment delivery, as well as a suitable monitoring strategy to properly calibrate the model, making this a rather time-intensive model (Elliot et al 1999; Fu et al 2010).

The second generation of the Kinematic Runoff and Erosion Model (KINEROS2) is a physics-based sediment production model designed to deliver event-based predictions (Smith et al 1995). Likewise designed originally for an agricultural application, this model has been used with some perceived success in predicting erosion on small-scale plots of unsealed roads, but larger scale use of this model is hindered by overlooking of hydrological dynamics within forest roads systems (i.e., advective flows) (Ziegler et al 2002; Fu et al 2010). Additionally, this model has not been tested to calculate sediment delivery to stream networks and, as a physics-based model, requires a large degree of data and calibration (Ziegler et al 2002; Fu et al 2010).

The Geomorphic Road Analysis and Inventory Package (GRAIP) is an empirical, GIS-based sediment delivery model developed by the United States Forest Service (USFS) Rocky

Mountain Research Station specifically for use on US National Forest unsealed roads (Cissel et al. 2012). This deterministic model, based on data collected by Luce and Black in Oregon, calculates annual sediment production for each road segment based on the segments length and slope, with multipliers based on road surface, vegetation cover, and an annual base erosion rate (Luce and Black 1999, 2001; Cissel et al. 2012). GRAIP has been successfully applied to National Forest roads throughout the northern Rockies and Pacific Northwest (Al-Chokhachy et al 2016; Goode et al 2012; Rieman and Wallenburn 2015; Cabrera et al 2015).

GRAIP focuses on three components for the development of an output model: road prism and ditches, drainage points, and the type of surface and flow path of water that has drained from the road surface (Cissel et al. 2012). These components weighed against an annual average erosion baserate, ideally determined by local climatic variables (Cissel et al. 2012). A thesis from Whitman College in 2010 examined GRAIP results and found that distance of the drain point from a stream, type of drain point, and elevation of the drain point are the most important factors in determining the probability of hydrologic connectivity to the stream (McCune 2010). This method requires the use of readily available GIS layers, such as the USFS Road Core and Digital Elevation Models (DEM's) (USDA 2019; USGS 2019). However, this method also requires a comprehensive GPS-collected road inventory, designed to determine, among other things, road condition, water entry to the road prism, and points where water and sediment leave the roads surface to travel down the hillslope (Black et al. 2012).

GRAIP-Lite is a stripped-down, easy to use version of GRAIP. It relies on several assumptions, negating the need for field-collected data (Nelson 2019). This model uses the results from several GRAIP analyses to infer certain information about readily available GIS layers (Nelson 2019, Cissel et al 2011). Annual sediment production is determined for each individual road segment using the equation:

$$E = B\ x\ R\ x\ S\ x\ V$$

where *E* is total annual sediment production for the road segment (kg/year), *B* is the erosion baserate (kg/year/m), *R* is the elevation difference of the road segment (m), *S* is the road surfacing factor, and *V* is the vegetation cover factor (Nelson 2019). Sediment delivery for each particular drain point is calculated fractionally based on the modeled flow distance to the stream and the length of road drained (Nelson 2019).

A study by the Southwest Crown of the Continent Collaborative compared results from both GRAIP and GRAIP-Lite to water quality monitoring by community scientists in 2013 (Rieman and Wallenburn 2014, 2015). Rieman and Wallenburn (2015) found a positive association between GRAIP-Lite analysis and previous GRAIP analysis, though a trend of over-prediction at lower sediment yields was observed in GRAIP-Lite. The study found little or no relationship between GRAIP and GRAIP-Lite model outputs and previous water quality monitoring data, however the original study focused sampling efforts on periods of high flows and therefore is not representative of annual averages that the GRAIP model estimates (Rieman and Wallenburn 2015, 2014).

An uncalibrated GRAIP-Lite model needs only a DEM and road line data; even if crucial parameters within the road data are missing, assumptions will be made so that model output can be generated (Nelson 2019). It is also possible to calibrate a GRAIP-Lite model with information collected in the field or otherwise, allowing users to add some local variation without performing an exhaustive inventory (Nelson 2019). Packaged calibration options include adding a point shapefile of 'observed drain points' and/or adding a polygon shapefile of user-defined ‘calibration zones’ which determine the erosion baserate used in the sediment production calculation; ‘calibration zones’ require a certain amount of field data to define (Nelson 2019).

In an attempt to assist conservation efforts in the decision-making process, the objective of this study is to analyze the viability of utilizing contributed community science data within a readily available sedimentation model on two unsealed National Forest roads. GRAIP-Lite was selected based on its suitability for National Forest roads, accessibility with minimal field data, and the ability to calibrate with observed drain points. This study will focus on the effects of adding additional GPS-collected drainage points to the GRAIP-Lite model.

Methods

Volunteer community scientists in Western North Carolina were trained to identify, measure, and catalog drainage features on National Forest roads and trails (Hansen et al forthcoming). Drainage and road condition data collected and submitted by Trout Unlimited community scientists using the Survey 123 app were automatically uploaded as a point shapefile to ArcGIS Online (Hansen et al forthcoming) and were formatted for inclusion in the GRAIP-Lite model.

A snapshot of community science data from the TU Western NC Trail/Road Sedimentation Survey from January 10, 2020 was examined and two roads were selected to model. A total of three models were developed for each forest road. The first two models fell within the GRAIP-Lite methodology: 1) Basic run and 2) Calibrated run including community science observed drain points. Based on preliminary results from the Basic and Calibrated models, a third model run was completed using only community science observed drain points, 3) Observed drain points only.

Study Areas

TU sedimentation surveys were focused within two research areas in Western North Carolina: Wilson Creek watershed & an area that is referred to as "Sky Island" (Figure 3-1, Hansen et al forthcoming). One road from each focal area was selected.

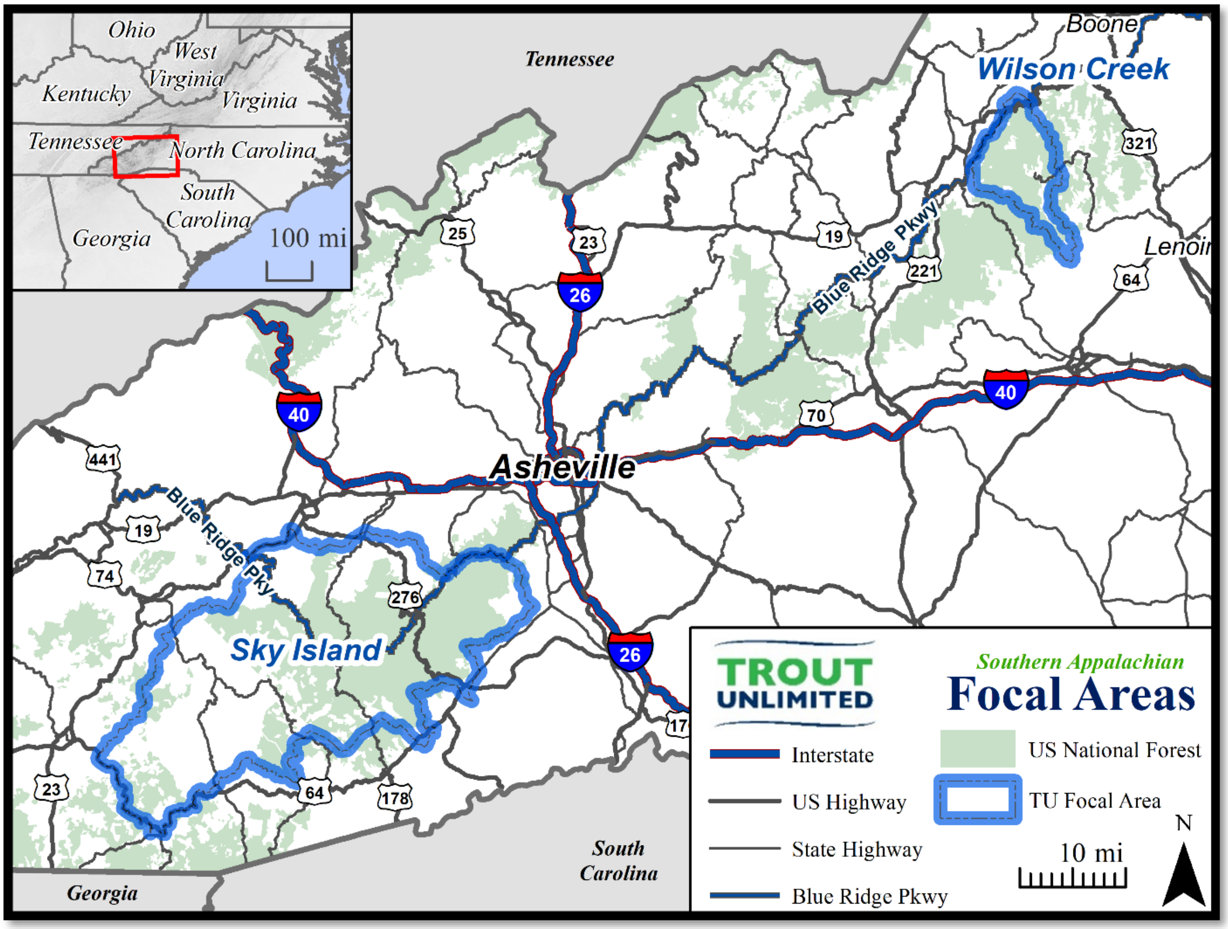

Figure 3-1. Trout Unlimited focal areas in Western North Carolina

Wilson Creek (FS-192). Old House Gap Rd, also known as Forest Service Road 192 (FS-192), was chosen for analysis in the Wilson Creek focal area (Figure 3-2). FS-192 runs from Old House Gap south along Gragg Prong until intersecting with Roseboro Rd in the small community of Roseboro, NC. From there, Gragg Prong flows southward, draining into Lost Cove Creek, then Wilson Creek (HUC 030501010504) (Figure 3-2). FS-192 is an unmaintained road open to high-clearance vehicle traffic and hosts the Mountains-to-Sea Trail along its length. The road is mostly within the National Forest but runs adjacent to and very briefly on to private property (Figure 3-2). Nineteen sedimentation survey points on this road were collected during the course of three days: May 16, 2019, August 16, 2019, and August 29, 2019.

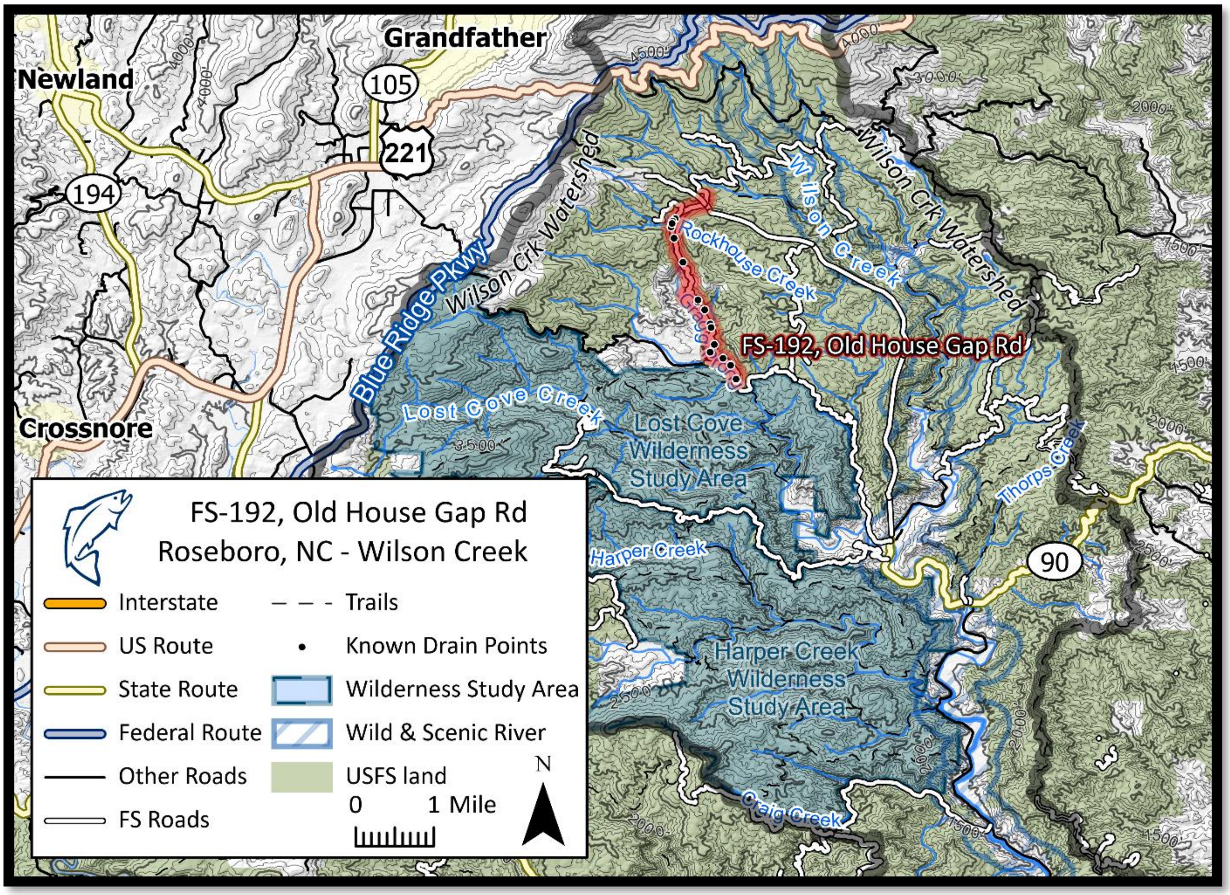

Figure 3-2. Forest Service Road 192, Old House Gap Rd, within the Wilson Creek focal area

Sky Island (FS-5000). Wash Creek Rd, also known as Forest Service Road 5000 (FS-5000), was chosen for analysis in the Sky Island focal area (Figure 3-3). FS-5000 runs from the Blue Ridge Parkway generally south along Wash Creek until intersecting with North Mills River Rd in the North Mills River Recreation Area in the town of Mills River, NC. Wash Creek drains into the North Fork Mills River (HUC 060101050403) and eventually into the French Broad

River (HUC 06010105) (Figure 3-3). FS-192 is a maintained gravel road open to vehicle traffic and is designated for passenger cars. The road is entirely within the National Forest and hosts a few trailheads for hiking, mountain biking, and pack/saddle animals (Figure 3-3). Sixty-five sedimentation survey points on this road were collected on November 18 and 19, 2019.

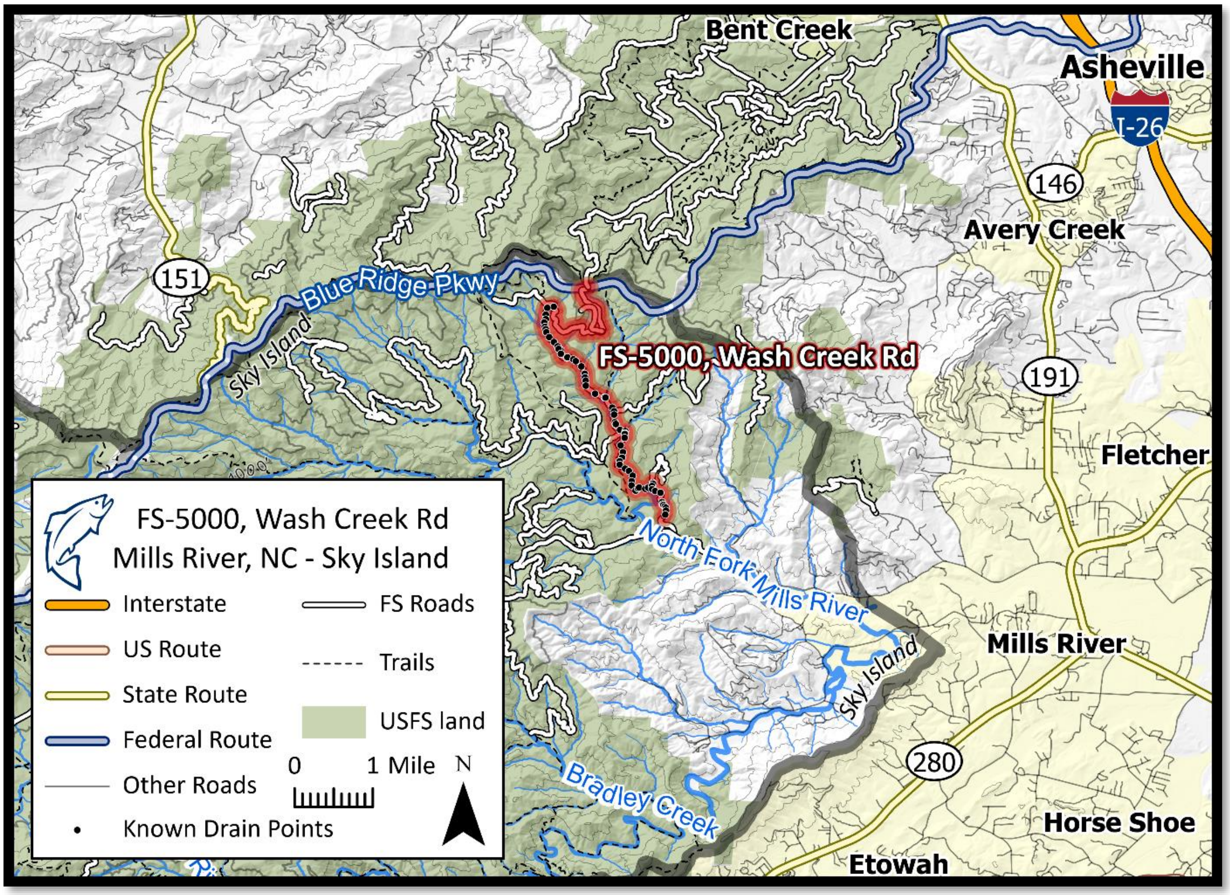

Figure 3-3. Forest Service Road 5000, Wash Creek Rd, Within the Sky Island focal area

GRAIP-Lite Model

Data and workspace. GRAIP-Lite is a freely downloadable model integrated with ArcGIS and comes prepackaged within the ArcHydro toolset (Nelson et al 2019). ArcGIS 10.5.1 was used and the ArcHyrdo toolset was downloaded and installed (Dartiguenave 2019). Two inputs are required for GRAIP-Lite, a 1/3 arc second resolution digital elevation model (DEM) for the area of examination and the National Forest System Roads layer (USFS RoadCore) (USFS 2019).

Elevation data for each area of study were downloaded from the US Geological Survey (USGS 2019) and all DEMs were reprojected to Universal Transverse Mercator (UTM) zone 17N to represent the study areas most accurately. In both areas, multiple DEMs were needed to cover the area; DEMs were combined using the *Workspace to Raster Dataset* tool in the *Data Management* toolbox. Overlapping areas were averaged during this process. Finally, to cut down on processing time DEMs were clipped to a bounding rectangle including each focal area. USFS RoadCore was also reprojected to UTM zone 17N and each study road, FS-192 and FS-5000, was exported to a separate layer.

To begin each new model, a new ArcGIS project (mxd) was created and saved in a unique folder and with a unique name. This step was essential to ensure that model outputs were calculated and written correctly. The GRAIP-Lite toolset was opened in the ArcToolbox; the two sub-toolboxes used during these processes were ‘1. Basic Run’ for the Basic run and ‘Processing’ for the Calibrated and Alternate runs (Figures 3-4, 3-5).

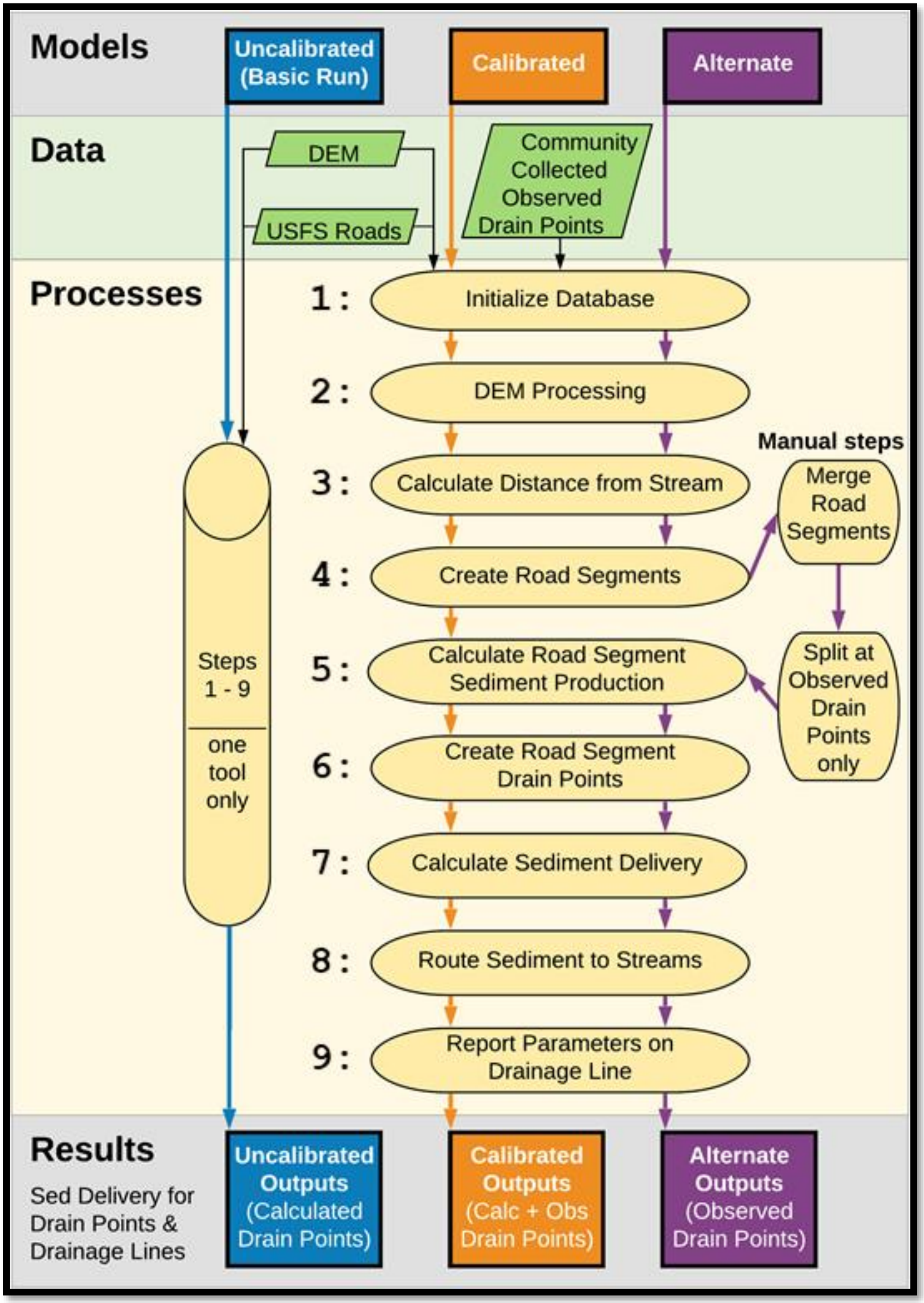

Figure 3-4. Steps for each of three GRAIP-Lite models used in this study

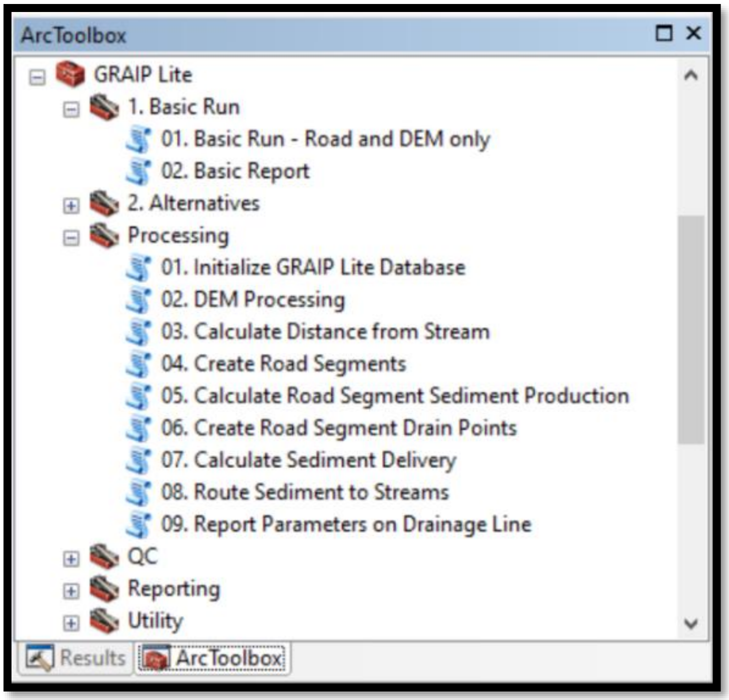

Figure 3-5. GRAIP-Lite toolset within the ArcHydro package in ArcGIS 10.5.1

Basic Run. The GRAIP-Lite Basic run is straight forward and can be easily run by a moderate GIS user. The tool script for a Basic run requires only two inputs: 1) 'Input Road,' and 2) 'Input DEM'; 'Target Geodatabase Directory' and 'Target Geodatabase Name' are populated automatically as long as the project has already been saved appropriately (Figures 3-4, 3-6). A box to 'QC Road' is also automatically populated to ensure that the road data being used meets the expected standards.

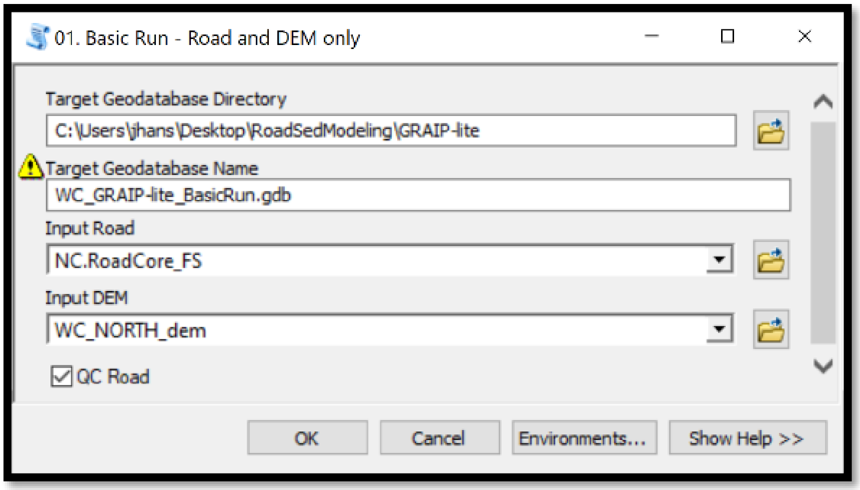

Figure 3-6. GRAIP-Lite tool script ‘1. Basic Run’ - ‘01. Basic Run - Road and DEM only’

The model run was initiated by clicking ‘OK’ and typically took in excess of one hour, depending on the number of roads and size of the study area. The process consisted of nine primary steps: 1) ‘Initialize GRAIP Lite Database,’ 2) ‘DEM Processing,’ 3) ‘Calculate Distance from Stream,’ 4) ‘Create Road Segments,’ 5) ‘Calculate Road Segment Sediment Production,’ 6) ‘Create Road Segment Drain Points,’ 7) ‘Calculate Sediment Delivery,’ 8) ‘Route Sediment to Streams,’ and 9) ‘Report Parameters on Drainage Line’ (Figure 3-4). In the Basic run, these steps ran automatically in the background.

Calibrated Run with observed drain points. GRAIP-Lite can be calibrated with additional data, if available. This was done for the second model at each site. In addition to the DEM and road layers, point data of drainage features collected by community scientists were added in the ‘Input Observed DrainPoint’ option (Figures 3-4, 3-7). The option to add a custom calibration zone was not used in this study because custom calibration zones were available only for sites in the Rocky Mountains. When processing a Calibrated run each step within the ‘Processing’ toolset in the GRAIP-Lite toolbox (Figure 3-4) was run separately.

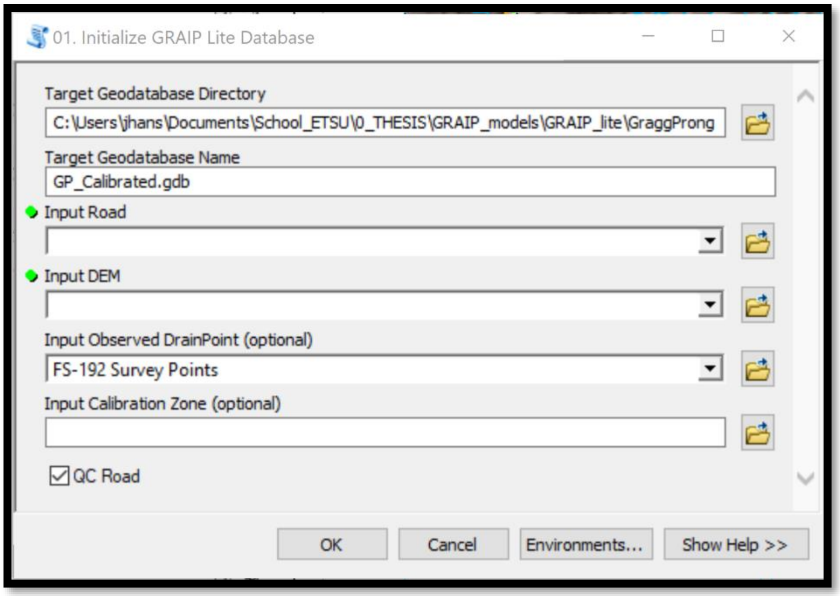

Figure 3-7. GRAIP-Lite tool script ‘Processing’ - ‘01. Initialize GRAIP Lite Database’

Alternate methodology: observed drain points only. Preliminary results from the GRAIP-Lite Basic run and Calibrated run were examined (Figure 3-8). It was noted that rather than replacing Basic run modeled drain point locations with observed locations, the Calibrated run tended towards adding the observed data as extra drainage points in addition to the modeled points. Because community scientists were trained to catalog all drainage features on a road, but the Calibrated run returned between three and ten times the number of observed drainage points, the third model scenario was developed (Figure 3-4).

This third model was completed in an attempt to address the presumed over-estimation of drain points by the GRAIP-Lite Basic and Calibrated runs. The first four tools were run the same as with the calibrated run, using observed drain points from the community science program. After step 4) ‘Create Road Segments,’ the data were manually altered to reflect only observed drainage points before continuing. To do this, road segments were merged into one road, then split by observed drain points (Figure 3-4). The result of this adjustment was the inclusion of only those drain points cataloged by community science volunteers. The remainder of the model tools (Figure 3-4) were run as with the Calibrated run.

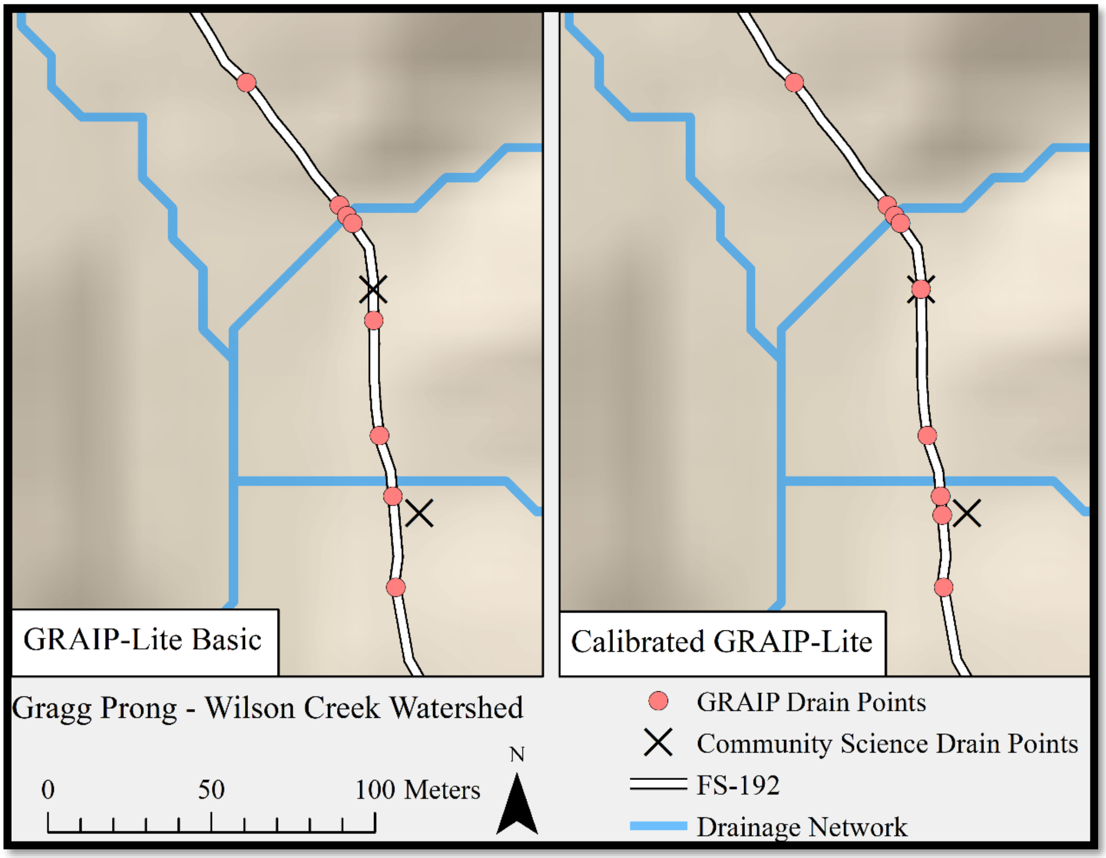

Figure 3-8. Preliminary results showing community science survey points (marked 'X') and GRAIP-Lite model drain point outputs for both Basic and Calibrated models. For the Calibrated model, a new drainage point was added near the southern survey point and a modeled drainage point was snapped to the northern survey point

Drain point data from the three model outputs were compared and examined statistically. Output quantities and locations were examined qualitatively for trends, and sediment delivery from road segments was compared for each model using Mann-Whitney U Tests.

Results

Three models were run for each study area, FS-192 and FS-5000. Each study area followed similar trends, with the Calibrated run showing the lowest sediment delivery and the Alternate run showing the highest sediment delivery by a wide margin (Table 3-1). All models show a trend of decreased drain point counts associated with increased sediment delivery, and FS-192 shows much higher sediment delivery than FS-5000 (Table 3-1). Statistically significant differences (p=0.015) were found between Basic and Calibrated runs for FS-5000 using a Mann–Whitney U test. No significant differences were found on FS-192.

Qualitative geospatial analysis found relatively similar trends of higher sediment production between the Basic and Calibrated runs at both sites (Figures 3-9, 3-10, 3-12, 3-13). When drain points were restricted to observed points, only a well-distributed and much higher proportion of higher sediment delivery zones (denoted by red circles) was observed (Figures 3-11, 3-14).

Table 3-1. Drain Point Statistics from GRAIP-Lite Model Outputs

		Basic Run	Calibrated	Observed only
FS-192 Old House Gap Rd Wilson Creek	Drain point count	156	165	17
	Average length of road drained (m)	29	27	301
	Average sediment delivery (kg/yr)	218	198	33,147
	Total sediment delivery (tonne/yr)	33.97	32.62	563.50
FS-5000 Wash Creek Rd Sky Island	Drain point count	195	242	66
	Average length of road drained (m)	40	32	132
	Average sediment delivery (kg/yr)	27	20	2,205
	Total sediment delivery (tonne/yr)	5.32	4.92	145.52

Old House Gap Rd (FS-192)

Basic Run. Modeled results from the GRAIP-Lite Basic run returned 156 drain points draining an average road length of 29 meters; each drain point contributed an average of 218 kilograms of sediment per year for a total sediment delivery of 33.97 tonnes per year (Table 3-1). Qualitative examination revealed that sediment delivery was highest near the bend in the northern section of the road where the stream is closest to the road, and in the middle section of the road where more drainage was present and intersecting the road, denoted by the two red circles along the surveyed road in Figure 3-9.

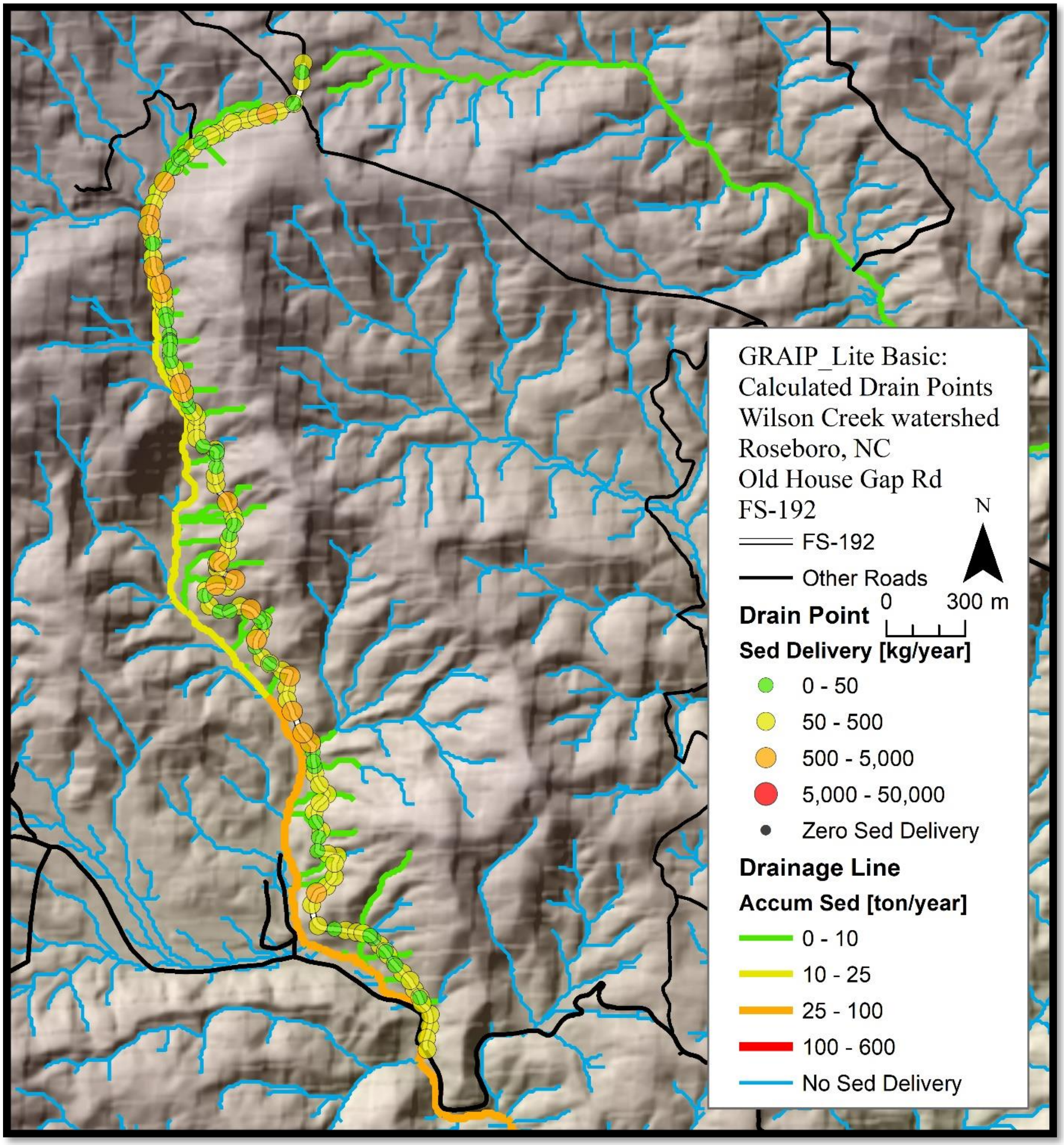

Figure 3-9. GRAIP-Lite Basic Run results for FS-192, Old House Gap Rd, including sediment delivery from road drain points and accumulated sediment delivery to drainage lines. Drain point locations were calculated solely by the model

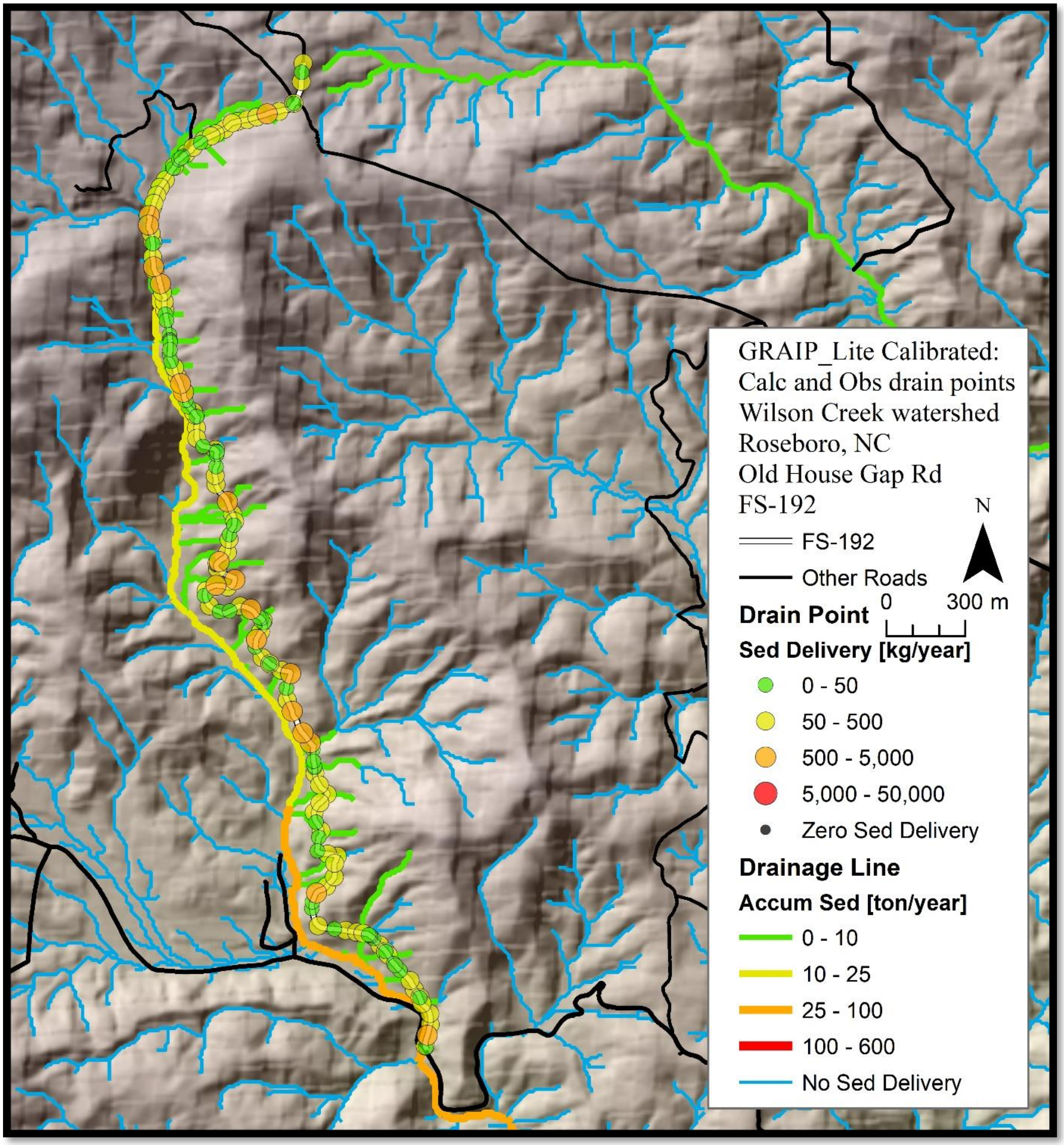

Figure 3-10. GRAIP-Lite Calibrated Run results for FS-192, Old House Gap Rd, including sediment delivery from road drain points and accumulated sediment delivery to drainage lines. Drain point locations were slightly influenced by community scientist collected drain points

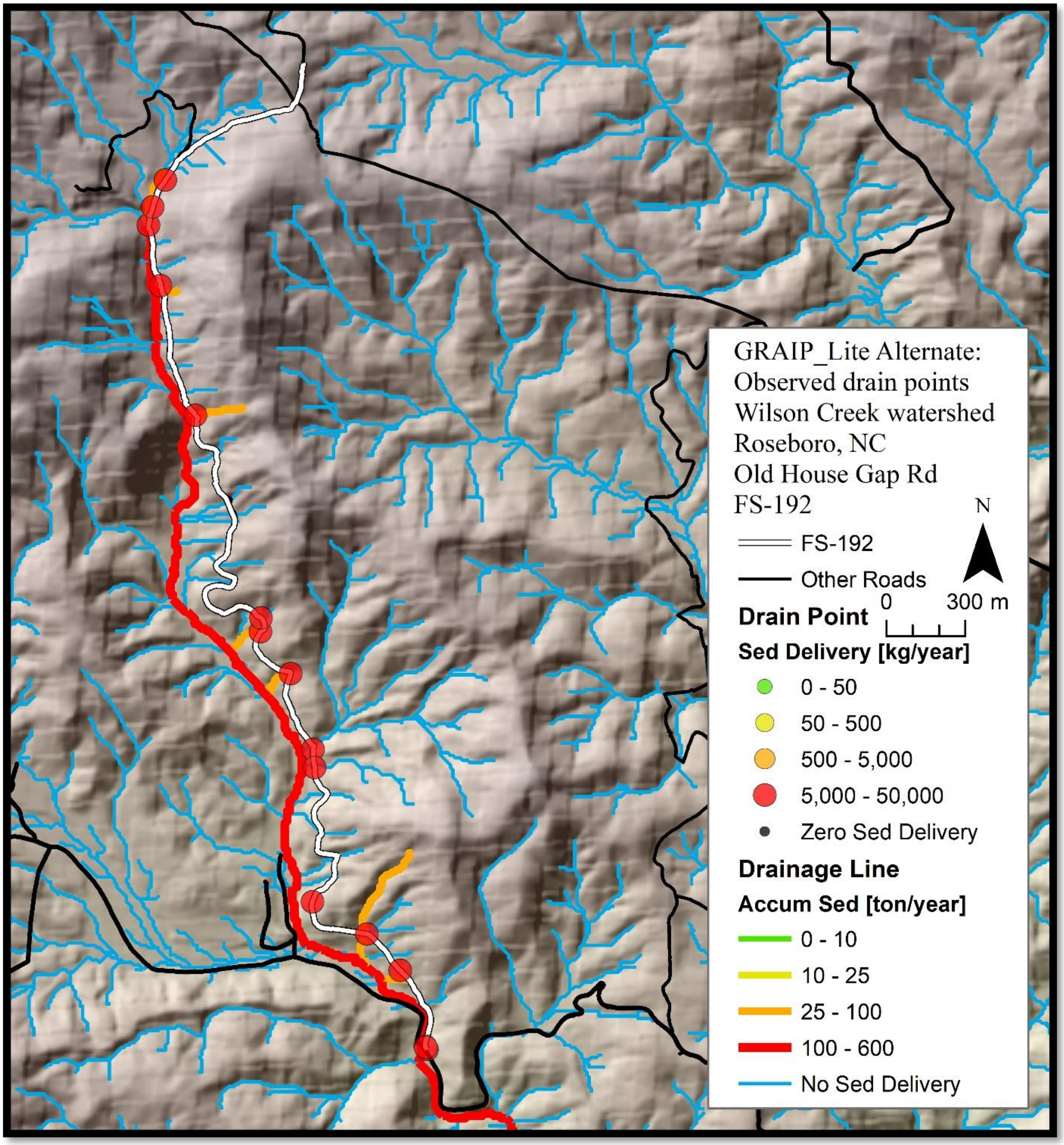

Figure 3-11. GRAIP-Lite Alternate Run results for FS-192, Old House Gap Rd, including sediment delivery from road drain points and accumulated sediment delivery to drainage lines. Only community scientist collected drain points were used in this model

Calibrated Run. Modeled results from the GRAIP-Lite Calibrated run returned 165 drain points draining an road length average of 27 meters; each drain point contributed an average of 198 kilograms of sediment delivery per year for a total of 32.62 tonnes per year (Table 3-1). Qualitative examination revealed that sediment delivery was highest near the bend in the northern section of the road where the stream was closest to the road, as well as in the middle section of the road where more drainage was present and intersecting the road, denoted by the clusters of red and orange circles along the surveyed road in Figure 3-10.

Alternate Run. Modeled results from the GRAIP-Lite Alternate run returned 17 drain points draining an average road length of 301 meters; each drain point contributed an average of 33.15 tonnes of sediment delivery per year for a total of 563.50 tonnes per year (Table 3-1). Qualitative examination revealed that sediment delivery was extremely high wherever drain points existed, indicated by markedly higher sediment delivery values in Figure 3-11.

Wash Creek Rd (FS-5000)

Basic Run. Modeled results from the GRAIP-Lite Basic run returned 195 drain points draining an average road length of 40 meters; each drain point contributed an average of 27 kilograms of sediment delivery per year for a total of 5.32 tonnes per year (Table 3-1). Qualitative examination revealed that sediment delivery was highest near the bend in the northwestern section of the road, and the northern half of the road produced more sediment than the southern half, most notably near drainage confluences, denoted by the group of red circles along the bend and otherwise spread along the northern half of the surveyed road in Figure 3-12.

Calibrated Run. Modeled results from the GRAIP-Lite Calibrated run returned 242 drain points draining an average road length of 32 meters; each drain point contributed an average of 20 kilograms of sediment delivery per year for a total of 4.92 tonnes per year (Table 3-1).

Qualitative examination revealed that sediment delivery was highest near the bend in the northwestern section of the road and otherwise well-distributed, denoted by the group of red circles along the bend and otherwise spread evenly along the surveyed road in Figure 3-13. Statistically significant differences (p=0.015) were found between the Basic and Calibrated runs for FS-5000 using a Mann-Whitney U Test.

Alternate Run. Modeled results from the GRAIP-Lite Alternate run returned 66 drain points draining an average road length of 132 meters; each drain point contributed an average of 2.21 tonnes of sediment delivery per year for a total of 145.52 tonnes per year (Table 3-1). Qualitative examination revealed that sediment delivery was extremely high wherever drain points existed, indicated by markedly higher sediment delivery values in Figure 3-14.

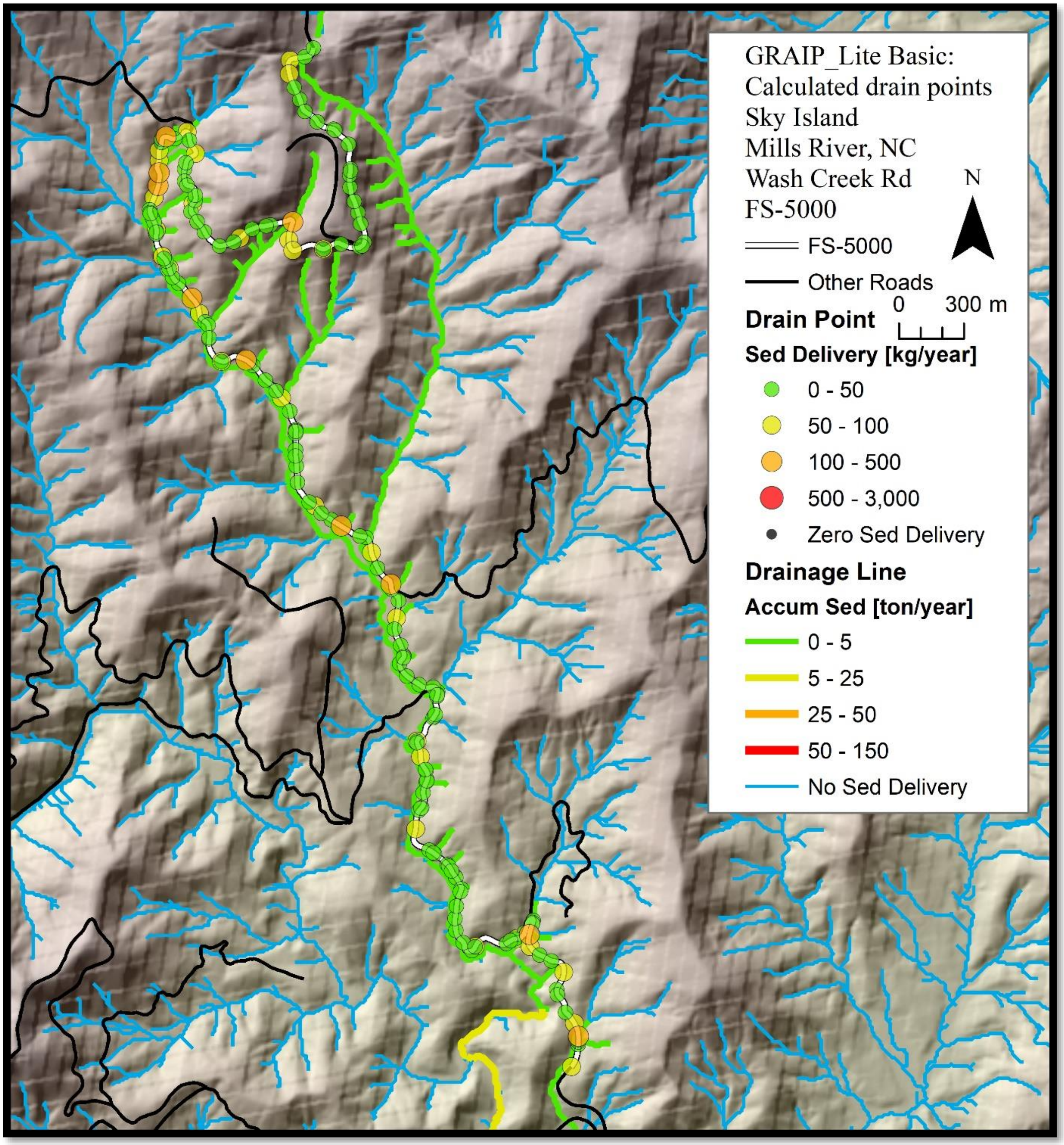

Figure 3-12. GRAIP-Lite Basic Run results for FS-5000, Wash Creek Rd, including sediment delivery from road drain points and accumulated sediment delivery to drainage lines. Drain point locations were calculated solely by the model

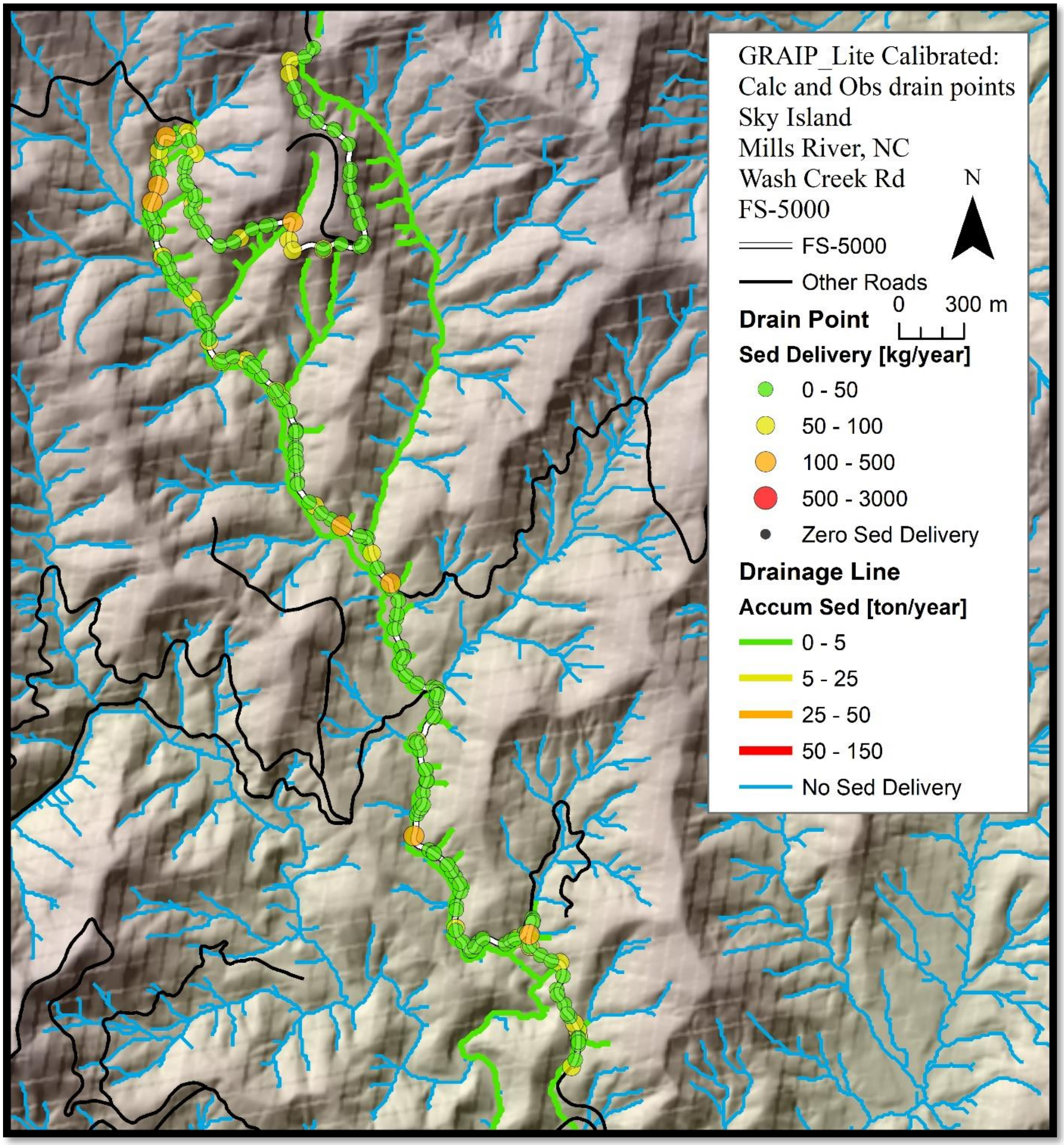

Figure 3-13. GRAIP-Lite Calibrated Run results for FS-5000, Wash Creek Rd, including sediment delivery from road drain points and accumulated sediment delivery to drainage lines. Drain point locations were slightly influenced by community scientist collected drain points

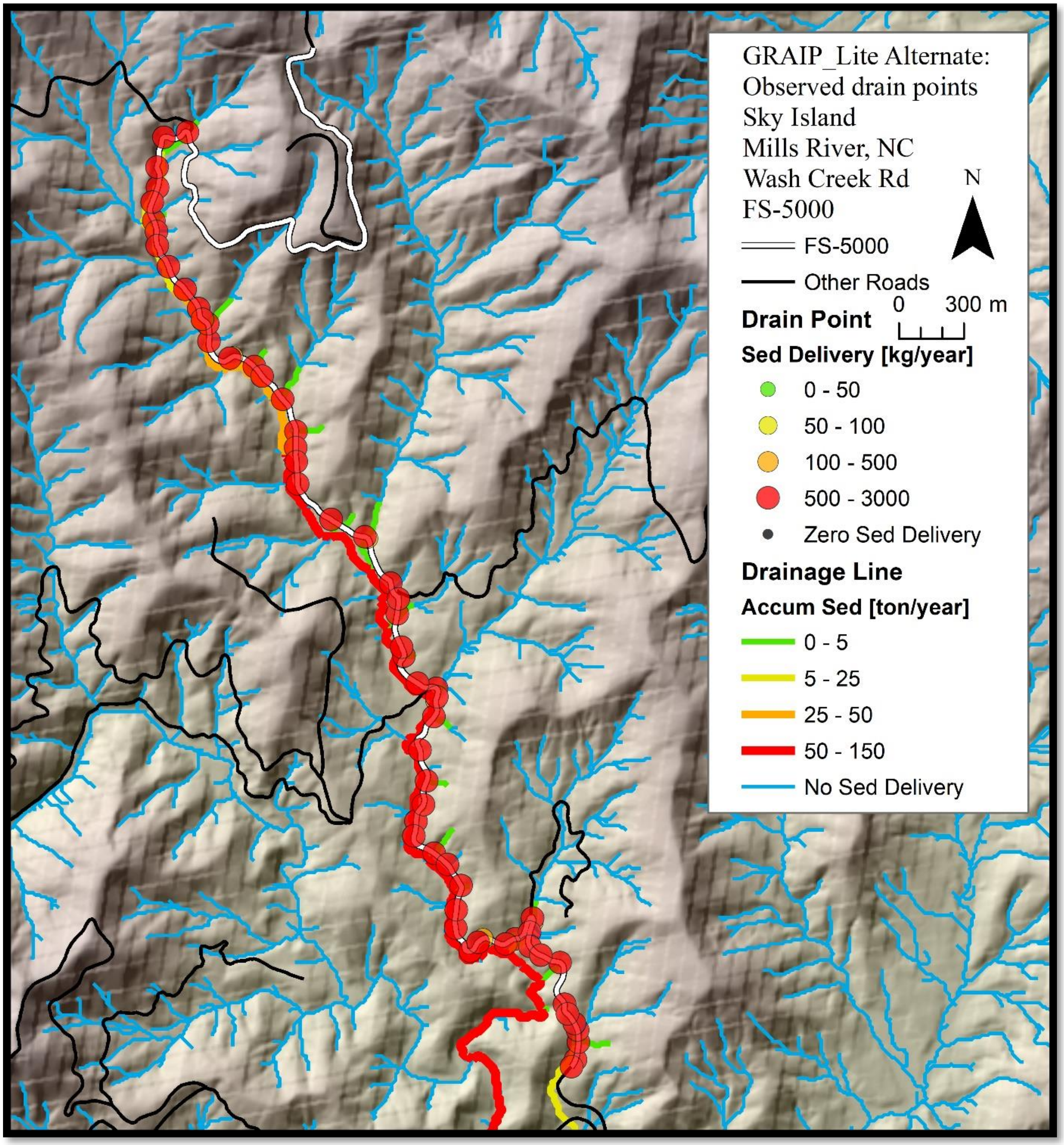

Figure 3-14. GRAIP-Lite Alternate Run results for FS-5000, Wash Creek Rd, including sediment delivery from road drain points and accumulated sediment delivery to drainage lines. Only community scientist collected drain points were used in this model

Discussion

In all models, FS-192 was estimated to deliver more sediment than FS-5000. This is likely due to differences in the roads which are accounted for in the USFS RoadCore layer. FS-192 is an unmaintained, native surface road suitable for high-clearance vehicles only; FS-5000 is a crushed gravel road maintained for passenger car accessibility (USFS 2019). Furthermore, differences may be even more pronounced; examination of the community science data shows that drainage features on FS-192 were generally recorded either ‘grade sag’ or ‘diversion ditch’ while those on FS-5000 were primarily cataloged as ‘culvert,’ which are less likely to deliver sediment to a stream (Hansen et al forthcoming).

A Mann-Whitney U Test showed statistically significant differences between the Basic and Calibrated runs of FS-5000, but not on FS-192. This may be due to the greater quantity of community science data at FS-5000 (66 drainage points) relative to FS-192 (17 drainage points), resulting in 24% and 6% increases, respectively, in the total number of drain points in the Calibrated runs. Calibration with community science data created a 7.5% reduction in the total annual sediment delivery for FS-5000 and a 4% reduction in the total annual sediment delivery for FS-192.

GRAIP-Lite results show a clear inverse correlation between the quantities of drainage points and sediment delivery. This corroborates Orndorff’s assertion that forest roads affect stream sedimentation by intercepting, concentrating, and diverting water (Orndorff 2017). Fewer drain points equates to longer flow distances on road sections, thereby allowing water to concentrate to a greater degree. This situation can also cause increased channeling on the road surface, adding additional travel distance potential thereby increasing delivery (Orndorff 2017).

Despite the fact that community scientists were trained to locate all drainage features on a road, calibration of the GRAIP-Lite model with these data increased the number of drain points at both study sites. This resulted in lower sediment delivery estimations once community science data were integrated into the model. Personal direct observation at FS-192 confirmed that for at least a large portion of the road all drainage features were cataloged by community scientists; long, gullied sections of FS-192 caused advective flows that drained infrequently. For this reason, the third, alternate model was run.

Returns from the Alternate run, however, show a sediment delivery on the order of 17 and 27 times higher than the Basic run for FS-192 and FS-5000, respectively. It seems unlikely that the total amount of sediment delivered to the streams would increase to that extent. However, without direct field measurements for model validation, it is unclear which model most accurately captures sediment delivery at either site.

According to Nelson et al, GRAIP-Lite calculates drain point locations "using catchment boundaries, stream crossings, calibration zones, known drainpoints, and pre-determined maximum distances" (Nelson et al 2019). No further literature was found discussing the placement of these drain points or purpose of the various deciding factors; for example, what is the "pre-determined maximum distance" and why is that distance used, and could it be meant strictly to temper results when road segments are too long? It seems clear, at least on the roads examined in this study, that GRAIP-Lite drastically overestimates the number of drain points, but it is not clear whether the modeled sediment delivery is consequently over- or under-estimated.

Study Limitations

The major limitations of this study stem from using readily available data and models without a method of validating model output using "on the ground" data. GRAIP-Lite was designed in the Rocky Mountains, where different environmental and anthropogenic conditions exist (Nelson et al 2019). Although several different calibration zones could be selected during model setup, none existed in Western NC and therefore the base erosion rate was used. Al-Chokhatchy et al (2016) assert that due to inherent regional differences, incorporating monitoring programs to calibrate sedimentation models with local data is necessary before results can be trusted to an acceptable degree.

Additionally, GRAIP-Lite models use a series of other assumptions based on over 77,000 drain points examined in GRAIP studies (Nelson et al 2019). While this provides a database for assuming averages and trends, GRAIP-Lite is likely to be less accurate in more detailed studies. Consequently, GRAIP-Lite is more appropriate for larger-scale projects, and watershed condition assessments at the HUC12 level show very similar results between GRAIP and GRAIP-Lite models (Nelson et al 2019). Although this model can be applied for use on smaller-scale areas, results from these studies become "an analysis of relative risk rather than of absolute values" (Nelson et al 2019).

While use of the full GRAIP model may provide more extensive information about sedimentation levels, field methods to gather the necessary input data are exhaustive and require specialized equipment such as a GPS unit capable of approximately 2-meter accuracy (Black et al 2012). It would be unreasonable to expect a community science program to train and outfit community members to a degree where accurate GRAIP surveys could be completed. Research comparing GRAIP and GRAIP-Lite model results for the same study area found correlation between results with an apparent GRAIP-Lite bias toward overestimating smaller amounts of sediment delivery (Rieman and Wallenburn 2015). Furthermore, the highest probability of sediment reaching the stream comes from three factors (distance from stream, type, and elevation of the drain point) for which data are much more easily collected than in a full GRAIP assessment (McCure 2010). This suggests that the benefits of running a full GRAIP model for these roads may be academic at best. However, a partial GRAIP survey designed to calibrate erosion base rates is recommended to provide more accurate sediment delivery estimates (Nelson et al 2019).

Conclusion

The objective of this study was to explore the viability of utilizing already available data within a readily available sedimentation model on two unsealed National Forest roads. This study provided a first look at the effects of including community science-derived drainage points in the GRAIP-Lite model. Statistically significant differences were found between Basic and Calibrated model results from one of the two study roads. While model results could not be validated using field data, which was beyond the scope of this research, results indicated that decreasing the quantity of drainage features on an unsealed forest road led to an increase in sediment delivery estimates in the GRAIP-Lite model, likely due to increased road segment length.

To examine this further, more research is needed to determine the methods of placement by GRAIP-Lite, as well as how restricting drain points to observed only affects the model outputs. Furthermore, proper calibration of local erosion base rates is recommended to provide more accurate sediment delivery estimates. Additionally, an on-the-ground study to measure sedimentation levels in the streams adjacent to the two study sites is recommended to provide data for model validation. Proper validation could allow for use of community science data within the GRAIP-Lite model to assess and estimate sedimentation levels to focus USFS management decisions in the places they are most needed.

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CHAPTER 4. CONCLUSION

Overview of Research Questions

Study I

Research questions. Can volunteer community members be effectively engaged to collect valuable, high-quality data on unsealed forest road erosion contributing to stream sedimentation?

Objectives. The objective of Study I is to train and actively engage concerned community members in data collection methods for examining and reporting erosion on unsealed forest roads. This dataset will ultimately impact on-the-ground conservation on USFS land.

Study II

Research questions. How does the inclusion of community-collected data into existing sedimentation models (GRAIP-Lite) affect the model's output, and what modifications can be done in an attempt to better represent conditions on the ground?

Objectives. The objective of Study II is to look at the viability of utilizing contributed community science data within a readily available sedimentation model on two unsealed National Forest roads. GRAIP-Lite was selected based on its suitability for National Forest roads, accessibility with minimal field data, and the ability to calibrate with observed drain points. This study will focus on the effects of adding addition of GPS collected drainage points to the GRAIP-Lite model.

Summary of Study I Methods and Findings

Community science can be an excellent tool to educate and involve the general public directly in the issues that affect them and collect more data than may be possible for small organizations. The Trout Unlimited Community Science Western NC Trail/Road Sedimentation

Survey was successful in collecting data on road and trail erosion within its areas of focus; a number of small modifications can be implemented to increase the effectiveness of this and similar programs.

Mass emails were ineffective and should not be relied upon. Instead, emails to established volunteers can be an effective communication method but should be subsidized with phone calls directly to individual volunteers. Development of a personal relationship between the coordinator and the community scientists can help the volunteers feel more connected to the project and therefore be more likely to collect more data. The best recruitment results came from direct requests to other organizations with similar goals to share the opportunity with their established volunteers. In-person networking is recommended to spread knowledge of, and garner interest in, the project. Additionally, a focus on recruitment of community scientists who can use sedimentation survey volunteer hours to meet another requirement is recommended to increase contribution and retention rates.

To help explain differences in the data between sites and between volunteers, a thorough quality control – ideally containing a certain amount of ground truthing – is needed. Furthermore, different volunteers should be encouraged to collect data at the same sites. The coordinator can use this redundancy as a form of quality control and choose to ground truth at locations where differences between volunteers are most apparent.

This study shows a strong connection between the type of drainage and the erosion level on the contributing road or trail. It also shows that drainage type, erosion level, and length of erosion associated with each drainage point affect the likelihood of sediment delivery to the waterway. Well-maintained and properly placed drainage can significantly improve conditions both on the road surface and in adjacent waterways.

Summary of Study II Methods and Findings

This study provided a first look at the effects of including community science-derived drainage points in the GRAIP-Lite model. Statistically significant differences were found between Basic and Calibrated model results from one of the two study roads. While model results could not be validated using field data, which was beyond the scope of this research, results indicated that decreasing the quantity of drainage features on an unsealed forest road led to an increase in sediment delivery estimates in the GRAIP-Lite model, likely due to increased road segment length.

To examine this further, more research is needed to determine the methods of placement by GRAIP-Lite, as well as how restricting drain points to observed only affects the model outputs. Furthermore, proper calibration of local erosion base rates is recommended to provide more accurate sediment delivery estimates. Additionally, an on-the-ground study to measure sedimentation levels in the streams adjacent to the two study sites is recommended to provide data for model validation.

Final Thoughts

Community-based monitoring is an effective way to collect on-the-ground observations about National Forest road erosion and stream sedimentation. Likewise, GIS-based sedimentation modeling is an effective way to get a quick and easy estimation about sediment transport and identify potential areas of concern. However, additional steps can be taken in both cases to increase the accuracy of information that is gathered. Additional quality control for community science data and better volunteer communication could increase the quality and quantity of data submitted through the Western NC Trail/Road Sedimentation Survey, and adequate calibration procedures for GRAIP-Lite would increase the accuracy of sedimentation estimate model outputs.

Without an appropriate field study within the study areas, it is unclear whether effects of calibrating GRAIP-Lite with community science data improved the accuracy of the model outputs. Future work in this area should include field-based observations of sediment loads within streams adjacent to forest roads with community science data available.

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APPENDICES

Appendix A: Trout Unlimited Sedimentation Survey Manual

TROUT UNLIMITED
PISGAH-NANTAHALA NATIONAL FOREST
NC WILDLIFE RESOURCES COMMISSION

Mobile App Reference Guide for Community Science Sedimentation Surveys on Trails & Roads

Accessing the Mobile App

1. Download **Survey123** field app to your mobile device:

   Download from iTunes Store >

   https://itunes.apple.com/us/app/survey123-for-arcgis/id993015031?mt=8

   Download from Google Play >

   https://play.google.com/store/apps/details?id=com.esri.survey123&hl=en

   Survey123 will ask you to login, but you can ignore that and close the app.

2. Link your device by visiting arcg.is/1v1au5 in your phone's internet browser and clicking on the *'Open in the Survey123 field app'* link. Survey will remain available in Survey123 now.

3. Start Collecting! Fields with red asterisk are mandatory.

Filling Out Observation Fields

Forest Service Ranger District Select Ranger District where you will be performing this survey.

Road/Trail Designation Type in the number or name of the trail or road being surveyed.

Surveyors Type in the first and last names of teammates on this survey with no spaces. At least two teammates are required for each survey.

Survey Date Select date on which the data for this survey is being collected.

Location Location is intended to be collected automatically through GPS signals. Record your location by touching the bullseye button. Verify point on map. Tap on map to place the point manually if point seems in error or GPS is not working. Survey can still be performed if GPS location is not working.

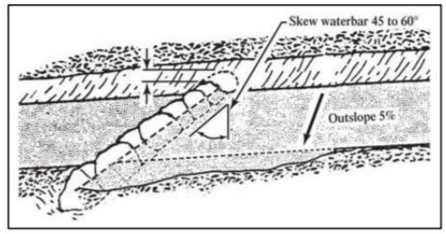
Try tapping on the bullseye (left) a couple of times, until you find the lowest ± value.

Location Description Describe location using landscape identifiers and map features.

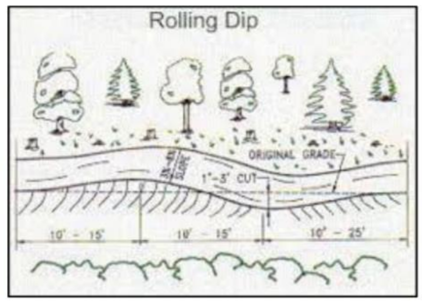
Prior to going into the field to perform assessment work, surveyors should familiarize themselves with the location of the survey using hard copy topographic maps or other electronic versions of topographic maps such as can be acquired through Avenza. It will be helpful for surveyors to carry such maps in the field as a supplement to Survey123.

Drainage Type When walking road or trail and obvious sediment is encountered that is leaving trail/road surface, select drainage feature type that is transporting sediment off the prism. (The terms prism and trail/road are used interchangeably). The following two pages show examples of drainage features. If the feature does not fit one of these options, choose *'other'* and write a brief description.

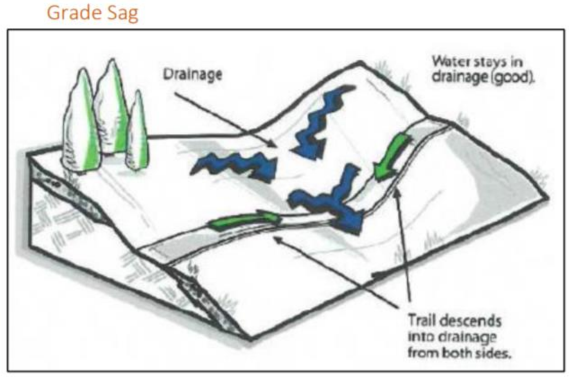
Waterbar



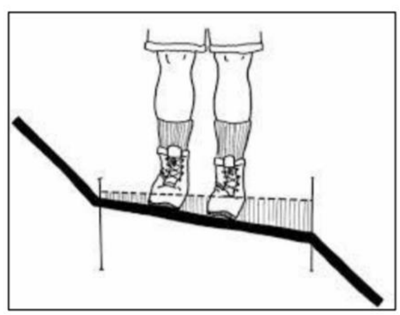
Rolling Dip



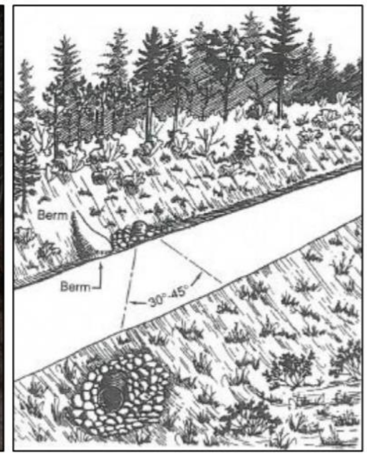
Grade Sag



Outslope

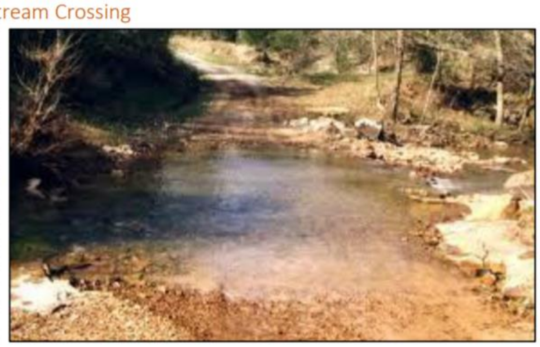


Culvert



Diversion Ditch

Stream Crossing



Surfacing Select predominate surface of road or trail at drainage feature including contributing area. If the surface does not fit one of these options, choose *'other'* and write a brief description.

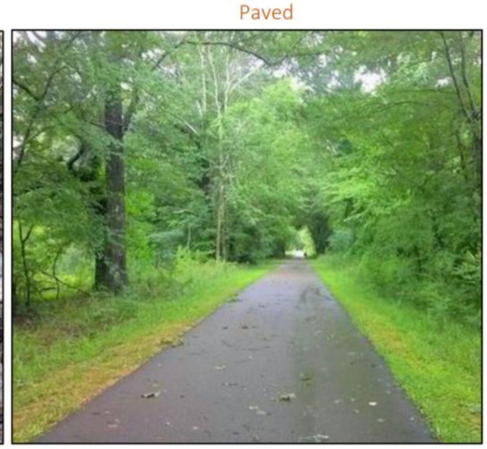
Native

Gravel

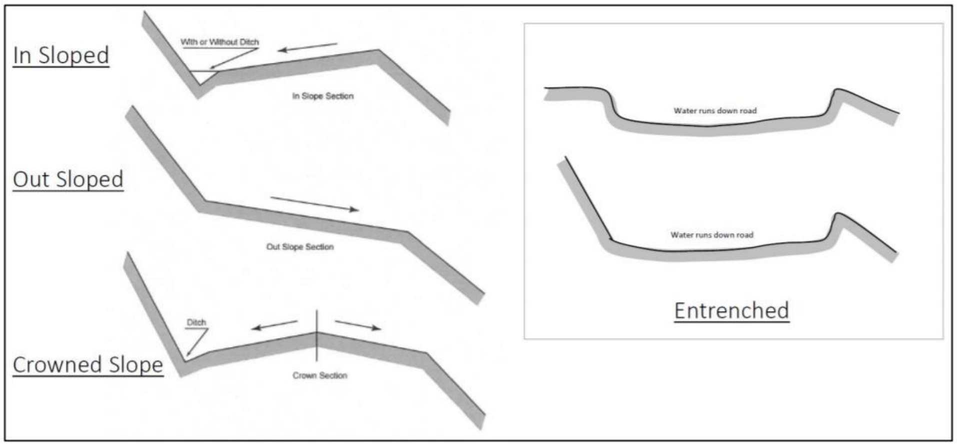
Washed Gravel

Rip-Rap Stone

Paved



Prism Shape Select category that best describes predominate shape of trail or road upslope & draining to drainage feature.

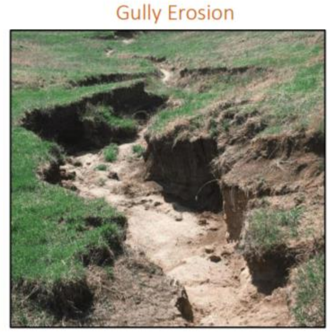


Prism Condition Select characterization that best describes predominate type of erosion on trail/road, if any, leading to drainage feature. In some cases, erosion may not be occurring on the prism but water is running off at the drainage feature and creating downslope erosive impacts. If the erosion does not fit one of these options, choose *'other'* and write a brief description.

Sheet Erosion

Rill Erosion

Gully Erosion



Stable

Stable w/ Downslope Impact

Length of Erosion on Prism to Drainage (Feet) With tape measure or confident pacing or ocular estimate, record distance of erosion on the prism which contributes to the drainage feature. Erosion may occur along the entirety of the contributing upslope prism even to the next upslope drainage feature or topographic break. Or it may not. *Only record the length of the erosion*.

Sediment Travel Distance (Feet) Where sediment is leaving trail, use tape measure or confident pacing or ocular estimate to record distance from trail/road edge to extent of visible sediment. This may require 'bushwhacking' and disturbing leaf and duff layer to get below surface appearances.

> *Do not confuse naturally occurring fine soil sediments with sediment from contributing prism. We are concerned with how far the sediment from the road is travelling.*

Erosion Off Road/Trail Observe surrounding terrain adjacent to prism and drainage feature and record yes or no to other obvious erosion occurring off the road or trail being surveyed. Sometimes a hillslope or gully may be occurring in the landscape surrounding the trail or road and this field allows us to capture that data.

Sediment to Stream Record yes or no to whether sediment from the trail/road and drainage feature being surveyed or that is occurring off the road or trail is making its way to a stream.

Sediment Plume in Channel from Drainage At stream, identify whether a sediment plume from same or similar sediment particles as evident on the trail or road is in the steam or stream bed. Record yes or no.

Cobble Embeddedness (Optional) If stream access is easy enough at location where sediment was observed entering the stream, surveyor is encouraged to perform cobble embeddedness measure at most immediate riffle[1] downstream of entry point of trail/road sediment. Record cobble whether embeddedness is less than or greater than 35% of cobble surface area.

[1]A riffle is a portion of a river or stream that is shallow with a rough bottom, causing turbulence and forming ripples on the water's surface. (http://worldlandforms.com)

> *There may be no direct correlation between sedimentation from the prism surveyed to the cobble embeddedness measure but this information, collected at various points in the stream, can help characterize sedimentation and riffle habitat in the watershed.*

Image of Sedimentation Source (Optional) Take a photograph depicting either erosion on the trail /road surveyed or the sediment travel to the stream. Limited to one photograph.

Check Mark Click check at bottom of survey to send

> *Often, no cell service will be available in the locations you will be surveying. If this is the case,* ***Survey123*** *will save the survey in your outbox. Please remember to submit all surveys once service is available.*

Thank You for Your Contributions in Understanding Sedimentation in our Coldwater Streams

See the Results of Our Efforts by Visiting: arcg.is/1WfWLC

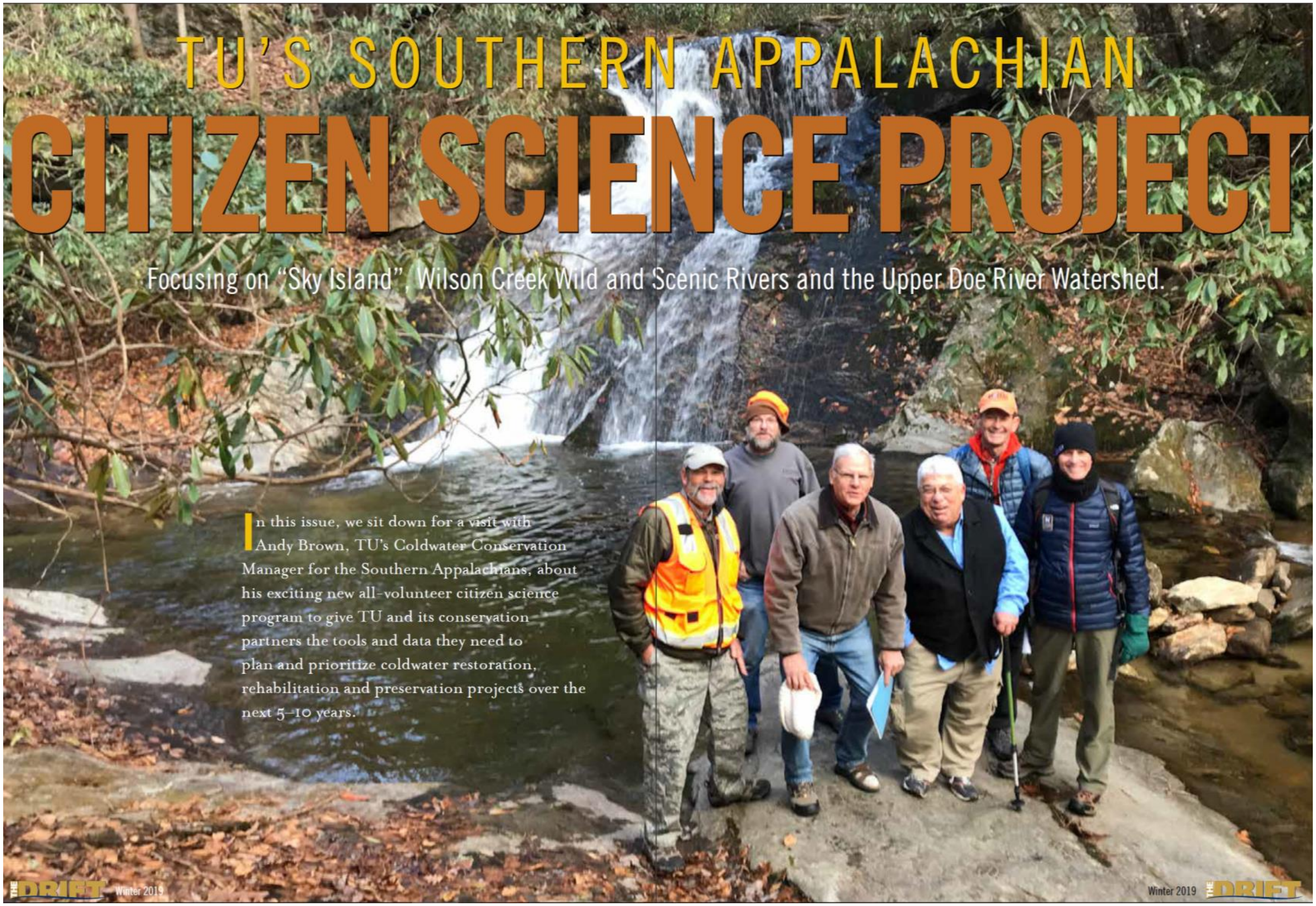
If You Have Questions, please contact TU Community Science Staff:

Jake Hansen | jake.hansen@tu.org | (207) 423-1359

or

Andy Brown | andy.brown@tu.org | (828) 674-1067

Appendix B: Citizen Science article in "The Drift"



TU'S SOUTHERN APPALACHIAN

CITIZEN SCIENCE PROJECT

Focusing on "Sky Island", Wilson Creek Wild and Scenic Rivers and the Upper Doe River Watershed.

In this issue, we sit down for a visit with Andy Brown, TU's Coldwater Conservation Manager for the Southern Appalachians, about his exciting new all-volunteer citizen science program to give TU and its conservation partners the tools and data they need to plan and prioritize coldwater restoration, rehabilitation and preservation projects over the next 5–10 years.

THE DRIFT Winter 2019

Winter 2019 THE DRIFT

Please tell us a little more about this Citizen Science project.

Trout Unlimited is collaborating with the US Forest Service and NC Wildlife Resources Commission on a citizen science program to help fill important data and information gaps on coldwater species and habitat management issues in the southern Appalachians. We feel that we have a lot to offer in this collaboration — from the thousands of our members who may have an interest in learning and employing scientific protocols to aid in trout management to the ability to raise funds to help get surveys and assessments done, and ultimately conservation projects on the ground.

We are currently performing surveys and monitoring on two items: A) stream crossings to identify whether culverts, fords or bridges are barriers to fish passage; B) roads and trails to identify significant erosion and sedimentation sources that are delivering sediments to coldwater streams.

Ultimately we may also monitor water temperature and perform eDNA surveys to identify presence/absence of native brook trout on streams where we lack that information. The end game is to develop with the Forest Service and State Wildlife Agencies a list of priority conservation projects that we can help them construct over the coming 10 years or so.

Two such projects might include road or trail remediation or replacing stream crossings that are barriers to fish passage with aquatic organism passage (AOP) friendly stream crossings. There are other types of coldwater conservation projects that we might also engage in — from riparian and stream restoration to native brook trout re-introduction work.

We have two focal areas — the Wilson Creek Wild and Scenic River watershed in Avery and Caldwell Counties, NC; and an area that some of us are calling Sky Island. This name came about because of a need to describe the area that comprises the headwaters of Catheys Creek and the Davidson, N and S Fork Mills, Pigeon and Tuckaseigee Rivers in Transylvania, Henderson, Buncombe, Haywood and Jackson Counties.

We also want to monitor the site-specific and cumulative impact of our work and be able to tell the story of how our coldwater conservation projects are delivering benefits to trout, trout habitat, and the anglers and communities downstream who depend on cold, clean water and access to larger acres of habitat. Please note — while this is a program of Trout Unlimited, we are actively recruiting all types of people in the surrounding communities. A person does not have to be a member of TU to participate.

How did the idea for this project come about?

Soon after I was hired, I knew that I needed to focus my efforts in certain places in order to be most effective with my time and the resources available to me. The region I am responsible for includes north Georgia, east Tennessee, western North Carolina and upstate South Carolina. I am only one person but TU has over 30 chapters and thousands of members in this region — many of whom are equally as or more passionate and technically competent than I.

While speaking to various chapters in the region, many people asked me where and how they could get involved. So I was thinking about that while at the same time I was building a Native and Wild Trout Conservation Planning Map for Western NC using a lot of relevant ecological and socio-economic data. Some of the data sets selected for this mapping process included: native brook trout presence, native brook trout habitat patches, USFS roads and trails, stream crossings, USFS priority watersheds, and municipal water supplies among others.

Once my team put all of that together, we could see where some of the more robust native and wild trout populations exist combined with large acreages of high quality habitat. We could also see how the road and trail network bisected many of these habitat patches. And only

at a few places did we know if the stream crossing was blocking fish passage or not. And at other places we had heard reports from hikers or bikers of eroding trails delivering sediment to streams.

So it was a matter of trying to connect persons from TU interested in coldwater conservation with our agency partners who have needs for data and information that can help drive their management priorities. And we are doing just this. TU, National Forest in NC and NC Wildlife Commission staff are training volunteers on certain protocols. Some of those protocols are methods that we have developed. Others have been developed by other partners such as the Southeast Aquatic Resources Partnership.

Jeff Wright (TU's new hire in the area) and I are coordinating the volunteers' monitoring activities and guiding them into the areas where we have needs. TU's science team is managing the data in GIS.

Overall, what's the most important thing for this program to deliver? Tell us a little more about its goals and objectives.

Our end game is getting good, effective coldwater conservation on the ground. And hopefully in a manner where a

number of projects are constructed in the same watersheds so that each builds off the success of the other such that there is a net cumulative benefit at the bottom of the watershed.

So from that perspective — the citizen science is intended to deliver good conservation. But there are so many other goals. One of our goals is to engage effectively the TU membership who wants to be involved in work like this. Trout Unlimited speaks of ,One TU', which means that the staff-persons and the membership are all working together well.

That is my aim, and I must say that I am enjoying getting to know more of the TU membership in these on-the-ground activities and am excited about the capacity to do this work that we, as a grass-roots organization, actually have.

Another goal is that we want to bring demonstrably added-value to our US Forest Service and state wildlife agency partners. They bring incredible expertise. And at the same time, they have more to do than they can realistically get done. Our coldwater conservation missions overlap so well. TU gets a chance to not only help them get the work done but also to help drive where the work gets done, which is incredibly exciting.

And not only that but the volunteer hours and information generated by our citizen science program gives me a very strong platform to stand upon when I ask private and public funders to join us by investing in this high elevation, source-water conservation.

You know — while I call it coldwater conservation, the work that TU is doing is really SOURCE water conservation. We are helping our agency partners protect, clean up and steward the source waters upon which so many people downstream depend for their drinking water supplies, economies and recreational outlets.

So another outcome or goal that I want to achieve from the citizen science is an enhanced fundraising capacity.

What's the biggest challenge you've faced as you've pulled the project together?

Time. There really is only one of me and this work is really about relationship building. And relationships take time. I don't want to treat anyone as an object, such as a data-gatherer, who is a means to an end. Because as I've mentioned, there are many goals that we want this program to achieve.

But there is always a person behind the protocol. And these persons join together as groups in our training — all with different backgrounds and personal histories and different comfort levels with what we are teaching. And for this program to be successful, I need to invest in each one of them and be as responsive to them as much as possible even after a training. But its what I want to do. I think its hugely important, and at the same time, the citizen science program is one of several other of my core job responsibilities.

Is the project funded? If not, how can people contribute?

Both the Land of Sky and Pisgah Chapters of TU have pledged to contribute to the program for the next 3 years. We recently received a $57,000 grant from the NC Clean Water Management Trust Fund, in part to support the citizen science and the coldwater conservation plan for the Sky Island area. The National Forests in NC have contributed funding and in-kind services from their biological, hydrological and engineering staffs. The NC Wildlife Resources Commission is also contributing staff time to the project.

You've worked to build partnerships with other people and organizations. Tell us a little bit about them, and how they're pitching in.

Lorie Stroup is the Fisheries Biologist for the Pisgah National Forest. **Brady Dodd** is the Forest Hydrologist for the National Forests in NC. **Scott Loftis** is the Mountain Aquatic Habitat Coordinator for the NC Wildlife Resources Commission. **Jake Rash** is the Coldwater Research Coordinator for the NC Wildlife Resources Commission.

All four of these people have contributed significant time to survey design and methodology development as well as to the teaching on-the-ground of the protocols to our citizen scientists. Jake has helped tremendously in putting our sedimentation surveys into an electronic format for use on hand-held devices. Trout Unlimited's GIS Analyst **Matt Mayfield** is helping to manage the data on the back end and create maps and other visual displays. The project is also widely supported in the National Forests in NC office by the Forest Supervisor, **Allen Nicholas** and Staff Officer **Barry Jones**. USFS Engineering and Recreation staff will ultimately be involved as we develop and execute trail remediation and AOP projects. For AOP work specifically, we have partnered with the Southeast Aquatic Resources Partnership and have adopted their protocol for stream crossing survey work.

Our area is home to many active conservation groups. Have you looked at tying this program into other efforts, like Mountain True's water quality study?

I think it's great what other groups are doing. I am aware of Mountain True's work and would like to collaborate more with them. And there are even other groups out there doing similar things. At some point, there comes a time to simply ‚get started' while at the same time being welcome to adaptations and inclusions that might be necessary when we learn of other complimentary efforts. I think that is where we are. We are moving forward on our work with our specific objectives in mind, knowing full well that there are others who we could collaborate with and being open to those possibilities.

It's clear that the success of the program relies on volunteer involvement. Tell us more about the training you're offering for volunteers who want to participate.

I envision this being a 3 year program. We'll hold more trainings in the winter and spring of 2019. And probably some more in the summer and fall. Sky Island and Wilson Creek are our current focal areas. I am open to expanding in other areas as my own person time and sanity, as well as other resources will allow. The sedimentation survey trainings take about 5 hours. A person could do one training and be competent enough to employ the protocol in a team environment. For safety reasons foremost, we do require that each person who participates with us do the work with at least one other person. The stream crossing survey trainings take 1-1/2 day. We require at least 3 people join together in a team to do this work. When we employ the water temperature data collectors, that will likely require a two hour training.

Okay, so after the training what should a volunteer expect? How does the actual data collection take place and how is it reported?

Volunteers should expect to see in fairly real time the fruits of their efforts — combined with the larger program work — mapped in GIS and available for review. Volunteers will not be able to manipulate the data but can participate with me and our agency partners as we analyze the data and develop prioritizations. Some of these priority projects that we identify through this angler science effort might be tailor-made for a chapter to undertake on their own. And so some volunteers might get the opportunity to participate in a project from the initial data gathering through the planning and prioritization to the ultimate outcome of conservation on the ground.

How many TU chapters have provided volunteers so far? Are you recruiting from other groups, too?

Thus far, we have had participation from both South and North Carolina chapters. SC chapters include: Saluda and Mountain Bridge. NC chapters include: Tuckaseigee, Pisgah, Land of Sky, Hickory, Table Rock and Rocky River. I am recruiting from all TU chapters in NC and SC thus far.

I am also recruiting from various watershed groups and conservancies around the focal areas such as the Mills River Partnership, Watershed Association for the Tuckaseigee River, and Foothills Conservancy of North Carolina. Others are welcome to join us! I keep putting the word out.

How can we learn more? Are you willing to speak at TU chapter meetings, or are there handouts and other materials for interested volunteers?

I am willing to speak at chapter meetings. I have a flier that discusses briefly the program. But the best way for a person to get more information is to come to a training and get involved.

To learn more about the project, please visit **https://northcarolinatu.org/citizenscience** or contact Andy directly:

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abrown@tu.org
160 Zillicoa Street,
Asheville NC 28801

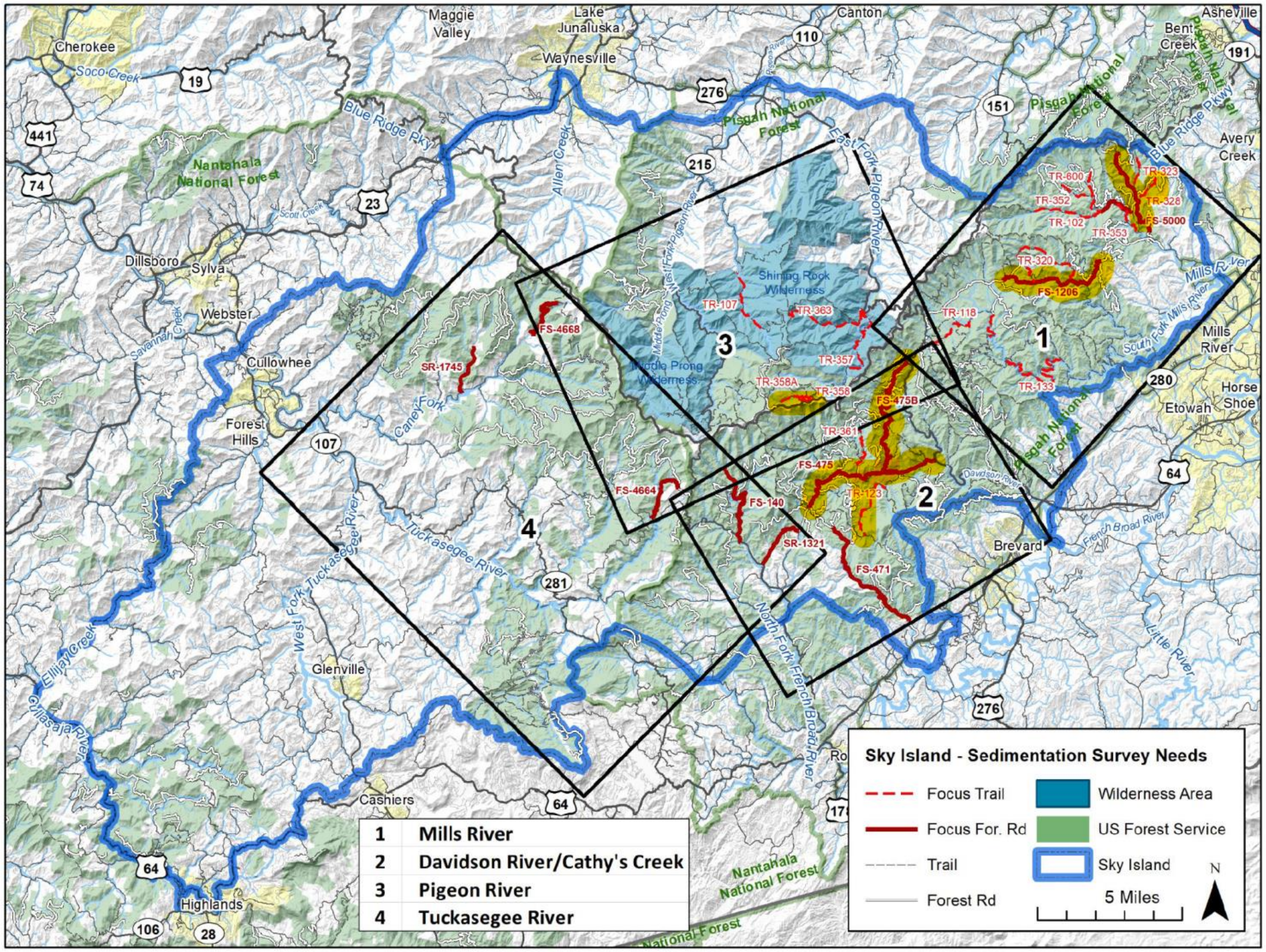
Appendix C: Sedimentation Surveys Priority Roads & Trails example

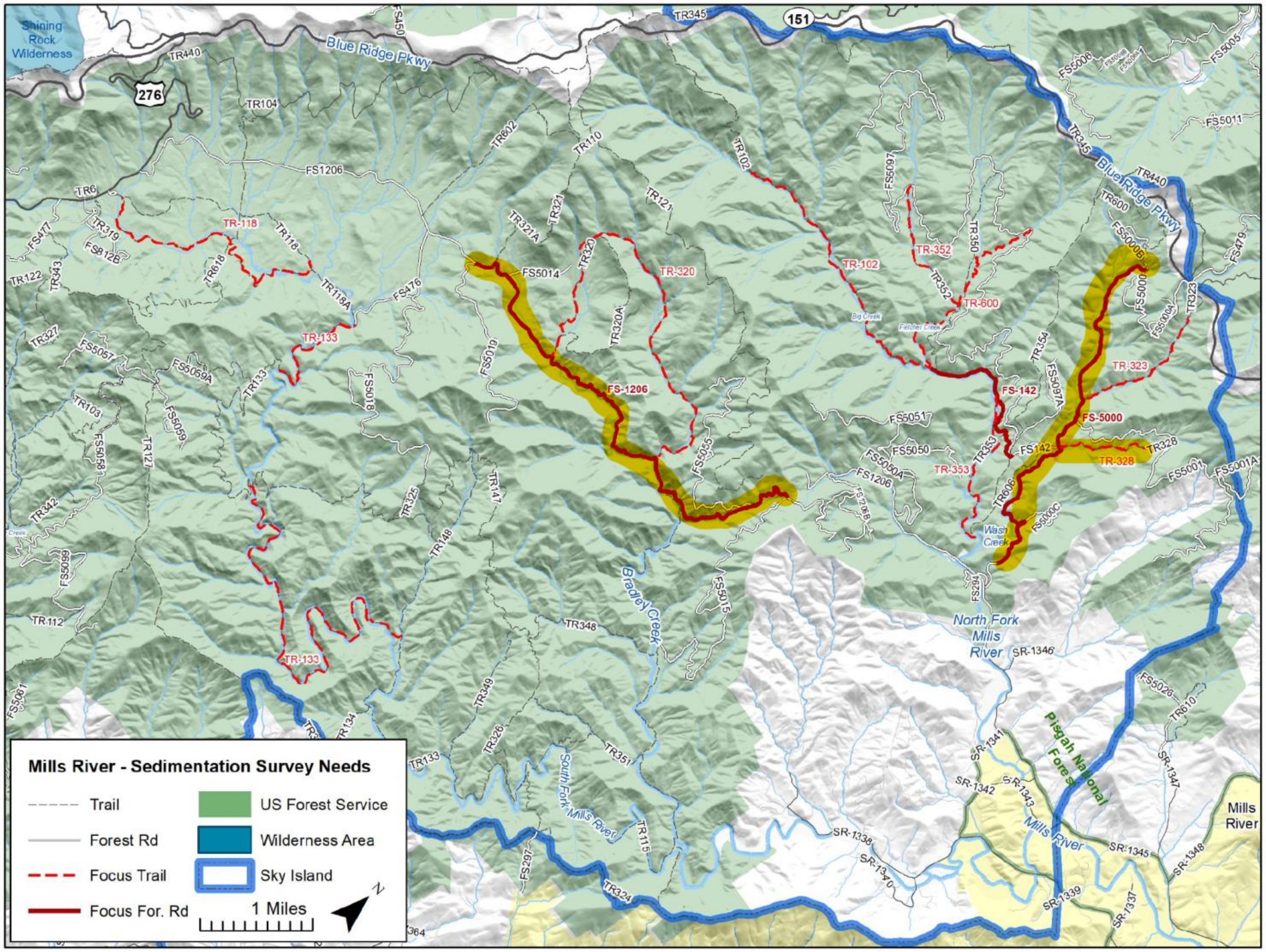
TROUT UNLIMITED
PISGAH-NANTAHALA NATIONAL FOREST
NC WILDLIFE RESOURCES COMMISSION

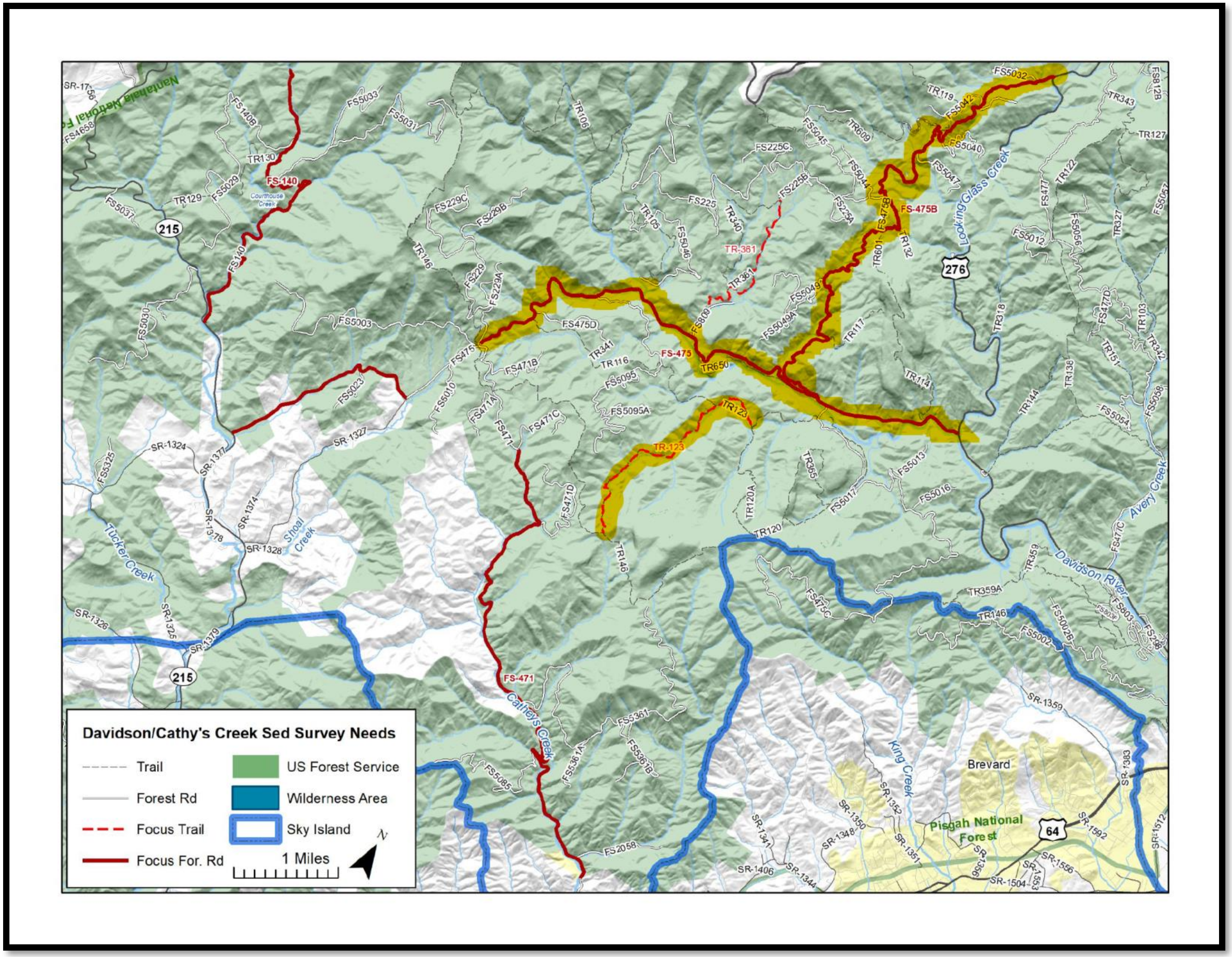
Sedimentation Surveys
Priority Roads & Trails

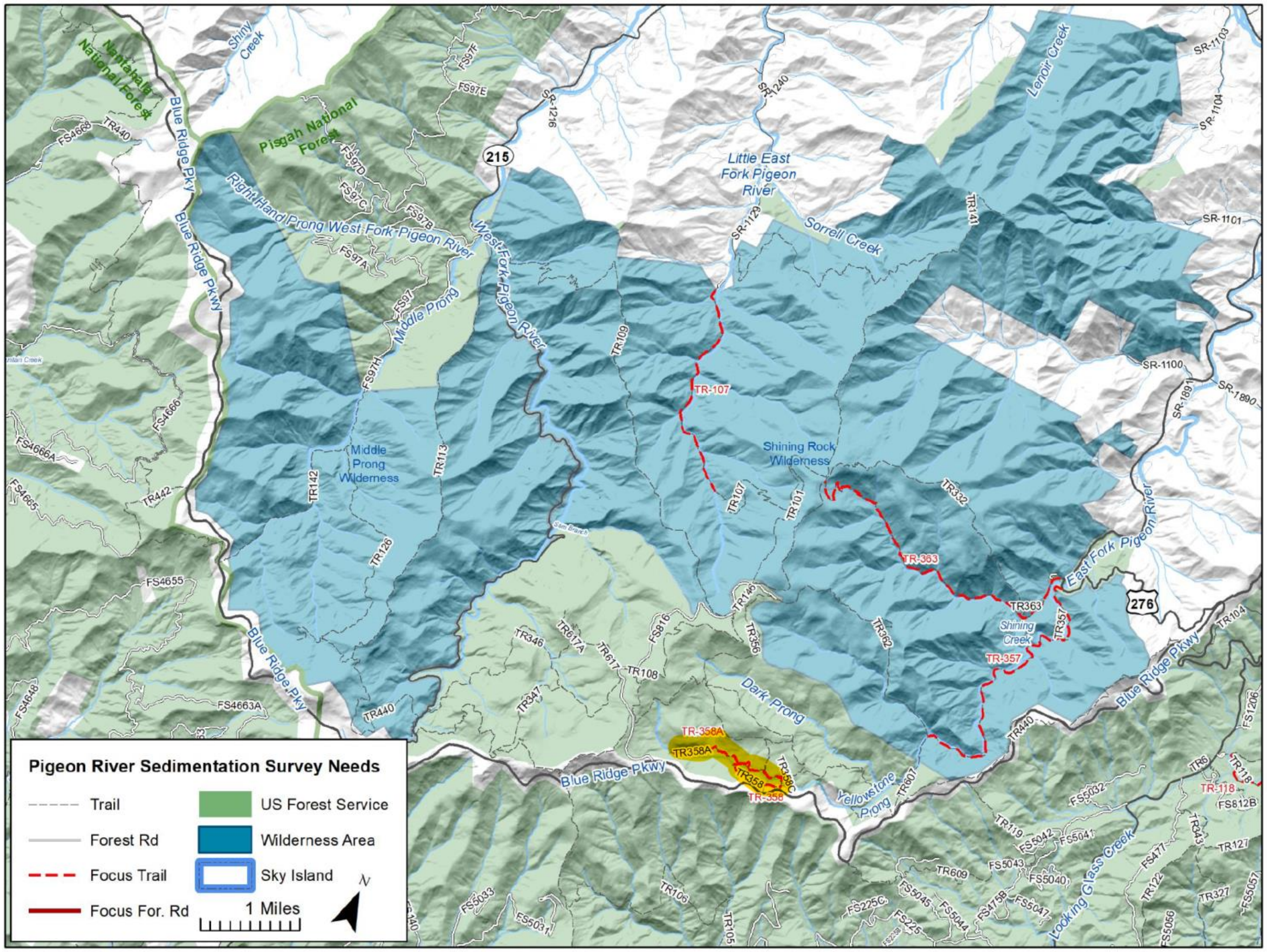
This list of top priorities for trails and roads to be surveyed for sedimentation is accompanied by 5 maps on the following pages for reference.

USFS #	Name	Streams Affected	Section Description	Rationale	Trout
TR-102	Big Creek Trail	Big Creek; Bee Branch	from terminus of Reservoir Road to where trail leaves creek	trail parallels & crosses creek multiple times	Brookies
TR-107	Little East Fork Trail	Little East Fork Pigeon River	from private land upstream to where trail leaves stream	trail parallels & crosses creek multiple times	Brookies
TR-118	Pink Beds Loop	South Mills River	entire length of trail beside stream	compliment to rain garden, high use area	
TR-123	Butter Gap Trail; Cat Gap Loop	Grogan Creek	from Butter Gap to Fish Hatchery	identify sedimentation contributions to fish hatchery intake	
TR-133	South Mills River Trail	South Mills River	from Cantrell Cr (Trail 148) to Trail 147	trail parallels & crosses creek multiple times	
TR-133	South Mills River Trail	South Mills River	from gate at FS Rd 176 downstream for 1.5 mile	trail parallels & crosses creek multiple times	
FS-140	Courthouse Creek Rd	Courthouse Creek	from Hwy 215 to terminus	road parallels stream; compliment to existing AOP	
~~FS-142~~	~~Hendersonville Reservoir Rd~~	North Mills River	from gate to terminus of road	road parallels creek; drinking water intake	
TR-320	Pilot Cove-Slate Rock	Slate Rock Creek	from Yellow Gap Rd to downstream section of 320A	trail parallels & crosses creek multiple times	Brookies
TR-323	Bad Fork Trail	Wash Creek	entire length of trail	trail parallels & crosses creek multiple times	Rainbows/Browns
TR-328	Bear Branch Trail	Wash Creek	entire length of trail	trail parallels & crosses creek multiple times	Rainbows/Browns
TR-352	Middle Fork	Middle Fork	from Trail 600 to FS Rd 5097	trail parallels & crosses creek multiple times	
TR-353	N Mills River Trail	North Mills River	from Hendersonville Reservoir Rd to Rec Area	trail parallels & crosses creek multiple times	
TR-357	Big East Fork Trail	Big East Fork Pigeon River	from Mtns to Sea Trail downstream to Hwy 276	trail parallels & crosses creek multiple times	
TR-358	Graveyard Fields Trail	Yellowstone Prong	entire length of trail, including 358A&B	trail parallels & crosses creek multiple times	
TR-361	Caney Bottom Loop	Caney Bottom Creek	from gated FS Rd 225B to Cove Creek group camp	complimentary data to new AOP on Cove Creek	
TR-363	Shining Rock Trail	Shining Rock Creek	from Art Loeb Trail to Hwy 276	trail parallels & crosses creek multiple times	Brookies
FS-471	Catheys Creek Road	Catheys Creek & tribs	from gated FS Rd 471C (Charles Cr) to Brevard water intake	Fills data for USFS WRAP; compliment to ongoing projects	
FS-475	Fish Hatchery Road	Davidson River	from Glocester Gap to intersection w/ Hwy 276	Pisgah TU Members Concern; Fish Hatchery; & Hi Rec Area	
FS-475B	Headwater Road	Looking Glass Tribs; Rockhouse Cr	from Fish Hatchery Road to Hwy 276	Complimentary data to barrier surveys; native & wild trout	
TR-600	Spencer Gap Trail	Spencer Branch; Fletcher Creek	from terminus of Reservoir Road to Neverending Road	trail parallels & crosses creek multiple times	Brookies
FS-1206	Yellow Gap Road	Bradley Creek	from Yellow Gap to Dividing Ridge	road parallels creek	
SR-1321	Indian Creek Road	Indian Creek	from FS Road 475 to Hwy 215	road parallels stream	
SR-1745	Chastine Creek Road	Chastine Creek	from SR1737 upstream to terminus	road parallels creek	Brookies
FS-4664	Camp Creek Road	Camp Creek	from gate at Cold Spring Gap Road to 1756	road parallels creek	
FS-4668	Mull Creek Road	Beechflat Cr; Mull Creek	from SR1737 upstream to terminus at Richland Balsam	road parallels creek	Brookies
FS-5000	Wash Creek Road	North Fork Mills River; Wash Cr	from gated FS Rd 5000B to N Mills Rec Area		

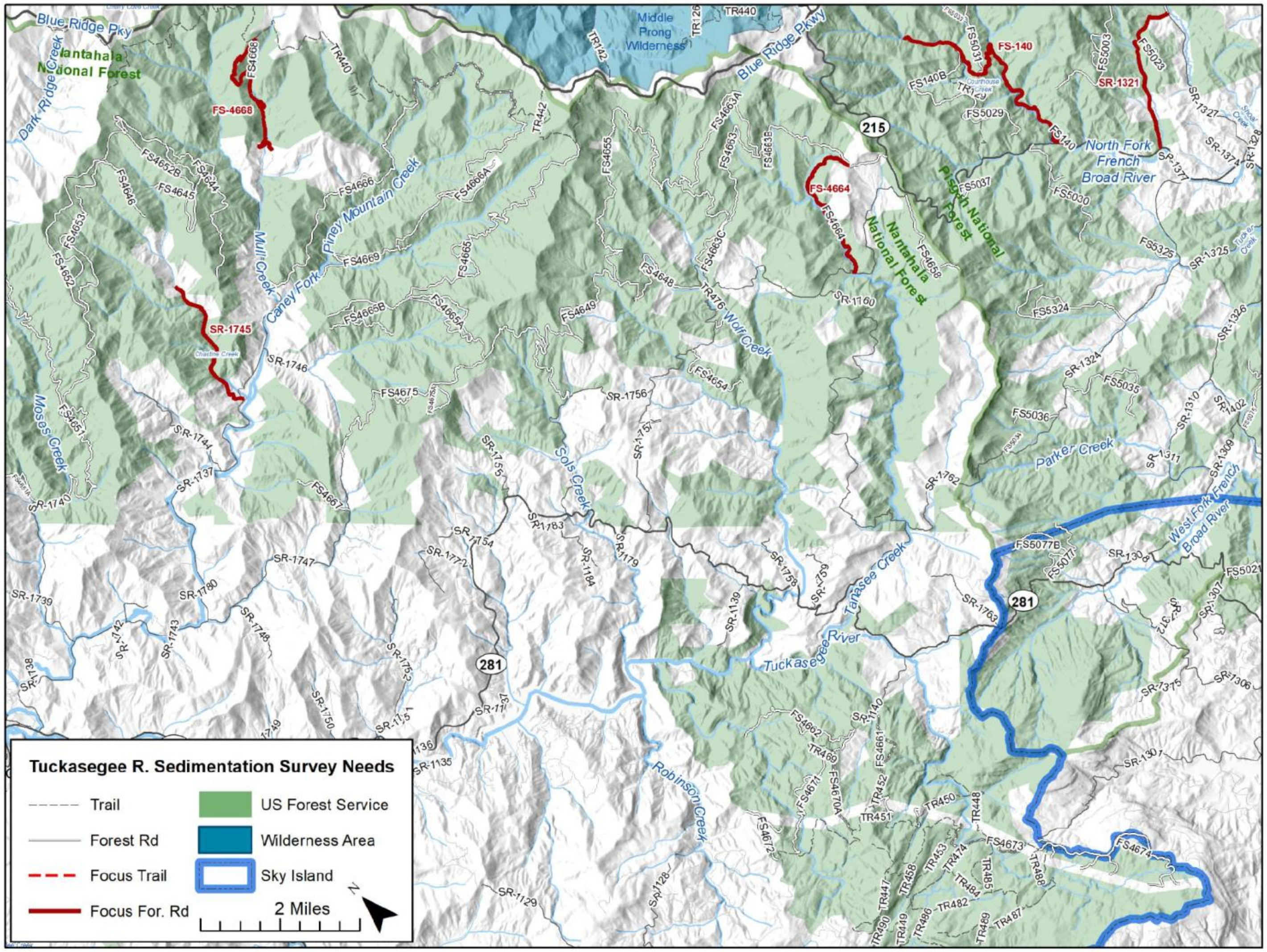

Sky Island - Sedimentation Survey Needs
Focus Trail
Focus For. Rd
Trail
Forest Rd
Wilderness Area
US Forest Service
Sky Island
5 Miles
N
1 Mills River
2 Davidson River/Cathy's Creek
3 Pigeon River
4 Tuckasegee River
Shining Rock Wilderness
Middle Prong Wilderness
Pisgah National Forest
Nantahala National Forest
Cherokee
Maggie Valley
Lake Junaluska
Waynesville
Canton
Asheville
Bent Creek
Avery Creek
Mills River
Etowah
Horse Shoe
Brevard
Dillsboro
Sylva
Webster
Cullowhee
Forest Hills
Glenville
Cashiers
Highlands
FS-5000
FS-1206
FS-4668
SR-1745
FS-475B
FS-475
FS-4664
FS-140
SR-1321
FS-471
TR-600
TR-323
TR-352
TR-328
TR-102
TR-353
TR-320
TR-118
TR-107
TR-363
TR-357
TR-358A
TR-358
TR-361
TR-123
TR-133


Mills River - Sedimentation Survey Needs
Trail
Forest Rd
Focus Trail
Focus For. Rd
US Forest Service
Wilderness Area
Sky Island
1 Miles
N
Shining Rock Wilderness
Blue Ridge Pkwy
Bradley Creek
North Fork Mills River
South Fork Mills River
Mills River
Pisgah National Forest
TR-118
TR-133
FS-1206
TR-320
TR-102
TR-352
TR-600
FS-142
TR-323
FS-5000
TR-328
TR-353


Davidson/Cathy's Creek Sed Survey Needs
Trail
Forest Rd
Focus Trail
Focus For. Rd
US Forest Service
Wilderness Area
Sky Island
1 Miles
FS-140
FS-475
FS-475B
FS-471
TR-123
TR-361
Looking Glass Creek
Davidson River
Avery Creek
King Creek
Tucker Creek
Shoal Creek
Cathey's Creek
Brevard
Pisgah National Forest



Pigeon River Sedimentation Survey Needs
Trail
Forest Rd
Focus Trail
Focus For. Rd
US Forest Service
Wilderness Area
Sky Island
1 Miles
Shining Rock Wilderness
Middle Prong Wilderness
Pisgah National Forest
Nantahala National Forest
Blue Ridge Pkwy
West Fork Pigeon River
Right Hand Prong West Fork Pigeon River
Middle Prong
Little East Fork Pigeon River
Sorrell Creek
Lenoir Creek
East Fork Pigeon River
Shining Creek
Dark Prong
Yellowstone Prong
Looking Glass Creek
Shiny Creek
TR-107
TR-363
TR-357
TR-358A
TR-358
TR-118
215
276



Tuckasegee R. Sedimentation Survey Needs
Trail
Forest Rd
Focus Trail
Focus For. Rd
US Forest Service
Wilderness Area
Sky Island
2 Miles
Blue Ridge Pkwy
Nantahala National Forest
Middle Prong Wilderness
Pisgah National Forest
Caney Fork
Piney Mountain Creek
Wolf Creek
Tuckasegee River
Robinson Creek
Moses Creek
Dark Ridge Creek
Mull Creek
Sols Creek
Tanasee Creek
Parker Creek
North Fork French Broad River
West Fork French Broad River
FS-4668
SR-1745
FS-4664
FS-140
SR-1321
215
281

VITA

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	Research Assistant, East Tennessee State University, College of Arts and Sciences, 2018-2019
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	GIS Specialist, Henderson County Land Records, Hendersonville, North Carolina, 2014-2017
Publications:	Hansen, J., James, T., and Luffman, I. (2019). "Monitoring E. coli Levels in Beaver Creek, Northeast Tennessee." Proceedings of the Twenty-Eighth Annual Tennessee Water Resources Symposium. Tennessee section of the American Water Resources Association.
	Reusch, D.N., and Hansen, J. (2017). "Geology of the Bald

Mountain-Saddleback Wind Range, West-Central Maine" in Johnson, B. and Eusden, J.D., ed., "Guidebook for Field Trips in Western Maine and Northern New Hampshire: New England Intercollegiate Geological Conference." Bates College. p. 119-134. https://doi.org/10.26780/2017.001.0008

Reusch, D.N., Hansen, J., and Cyr, A. (2012). "Microstratigraphy and cryptic thrusts of Bald Mountain, Wilton-Weld area, west-central Maine." Geological Society of Maine summer field trip (2012/8/4). field guide. 10 p.

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Honors and Awards: Michael D. Wilson Fellowship, 2010-2011

Best Student Poster, 37th Annual Colloquium of the Atlantic Geoscience Society, 2011